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NEW METHODS FOR THE DETERMINATION OF THE AVAILABILITY OF NITROGEN AND PHOSPHORUS TO PLANTS[1]

E. M. EMMERT[2]

IF a grower could find out in time what plant nutrient is lacking to make his crop do best, it would be a great help. The preliminary work reported here was an attempt to use simple tests requiring only a few minutes to determine deficiencies in the plant, and to determine whether these tests are reliable indicators of the ability of the soil to furnish nitrogen and phosphorus to the plant.

It was assumed that the nutrients found in the lower conducting tissues of the plant are a close approximation of the materials the plant is able to obtain from the soil, whereas the nutrients found in apical tissues would be such as had not been utilized or elaborated in the process of growth. Inasmuch as the nutrients derived by a growing plant from the soil must enter in solution through the stem, it seems reasonable that the concentration of a given nutrient in the conducting tissue of the stem should be directly proportional to the available supply of that nutrient from the soil. A measure of the content of nutrients in this conducting tissue, therefore, may be a better measure of the ability of the soil in which the plant is growing to supply nutrients than a chemical test of the soil itself. It seems probable, also, that an optimum content of nutrients in this kind of tissue should exist for the various stages of growth of each kind of crop regardless of the kind of soil in which the crop is growing. The work reported in this paper was done to test this hypothesis. The results are favorable and seem to justify thorough investigation of the question.

REASON FOR USE OF SOLUBLE N INSTEAD OF NITRATE N

The methods of analysis used were mainly those already described,[3] but with an important addition. Inasmuch as recent work has shown

[1]Contribution from the Department of Horticulture, University of Kentucky, Lexington, Ky. The investigation reported in this paper was made in connection with a project of the Kentucky Agricultural Experiment Station and is published by permission of the Director. Received for publication May 28, 1934.

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[3]EMMERT, E. M. Field method for estimating nitrate, phosphate and potassium in plants. Plant Phys., 7:315-321. 1932.

that other nitrogen compounds than nitrate may be absorbed and used by plants, it is proposed to substitute for the determination of nitrate, a determination of nitrogen in compounds soluble in 2% acetic acid, or "soluble nitrogen." The procedure for this determination is described below, and it was used in the analysis of lettuce reported herein.

DETERMINATION OF SOLUBLE NITROGEN

1. *To make the extract.*—Macerate thoroughly 1 to 5 grams (depending on the concentration of nutrients) of mature conducting tissue with a few tenths of a gram of acid-extracted charcoal[4] and exactly 10 cc of 2% acetic acid, and filter. Enough charcoal should be used to give a clear solution.

2. *The determination.*—Put 0.2 to 0.5 cc of the extract (depending on the amount needed to give a good color) into an ordinary 25-cc test tube. Add a granule of sodium chlorate about the size of a grain of wheat. From a pipette add rather rapidly 0.4 to 1.0 cc of fuming sulfuric acid (15% SO_3). The solution should boil and evolve chlorine. Excess of chloric acid must be decomposed or off-color tints will develop. It is decomposed if the solution boils vigorously and no chlorate is isolated on the sides of the tube. Blow and shake out the chlorine. As soon as the solution is clear add 0.2 to 0.5 cc of phenoldisulfonic acid and allow to stand a few seconds. Now add about 10 cc of water, neutralize with 40% sodium hydroxide until the maximum yellow color is produced, and make to 20 cc. Compare the color with a standard.

PRACTICABILITY OF THE TESTS

The soluble nitrogen and phosphate tests may be made in 5 to 10 minutes in the field. No heat or complicated equipment is needed. Besides test tubes, two reagents, a mortar and pestle, a funnel, and filter paper are needed for the extraction. For making the tests, a pipette, test tubes, and three reagents for soluble nitrogen and two for phosphorus are needed. Some scheme for comparing the color with the optimum color as determined for the particular crop being tested must be worked out. Experience is necessary to know what the colors should be. Once the optimum colors are determined for the various stages of a particular crop, it should be the same in all localities and for all types of soil. Calibration and modification to fit each type of soil, as is necessary with soil tests, should be unnecessary.

The part of the plant to be used will depend on the character of the growth. In all cases it should be a part which contains the most mature conducting tissue present. Of course a given part of the plant must be used in making comparisons, since various parts differ in their nutrient and moisture content.

The first important step is to determine the optimum, concentrations of nutrients for each stage of growth in the various crops.

RESULTS

Although there is some fluctuation in the data presented in Tables 1 and 2, the variations are not as large as the differences in soil type or fertilizer treatment. The data seem to show: (1) That soils of different

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[4]EMMERT, E. M. A method for the rapid determination of phosphate in fresh ·it tissues. Plant Phys., 5:413–417. 1930.

type differ widely in their capacity to furnish nitrogen and phosphorus to the conducting tissues of the plant; (2) that there is a correlation between the amount of nitrogen and phosphorus present and the yield; (3) that the effects of fertilizer treatments are shown by the tests on the plant; (4) that application of phosphate is accompanied by an increase in the amount of nitrate nitrogen in conducting tissues; and (5) that application of nitrate is accompanied by a reduction of phosphorus in the conducting tissues.

TABLE 1.—*Tomatoes, fall of 1932, in the greenhouse.**

Yield per plant, grams	Nutrients in petioles		N ÷ P	Kind of soil	Fertilizer in tons per acre†	
	Nitrate N, p.p.m.	Phosphate P, p.p.m.			Nitrate	Phosphate
1,767	551	222	2.5	Brown loam	0.20	0.35
1,476	844	342	2.5	Black loam	1.10	0.60
1,425	444	273	1.6	Black loam	0.00	0.00
1,397	764	152	5.0	Brown loam	0.40	0.25
1,340	731	75	9.7	Brown loam	0.60	0.00
1,283	632	266	2.4	Black loam	0.70	0.45
1,254	743	240	3.1	Black loam	0.63	0.30
1,026	755	39	19.4	Red clay	0.20	0.35
969	306	138	2.2	Brown loam	0.00	0.00
912	593	118	5.0	Sandy loam	0.40	0.50
884	704	28	25.1	Sandy loam	0.60	0.00
827	772	25	30.9	Red clay	0.50	0.00
799	684	122	5.6	Sandy loam	0.60	0.30
770	627	129	4.9	Red clay	0.20	0.65
656	152	38	4.0	Sandy loam	0.00	0.00
371	137	49	2.8	Red clay	0.00	0.00

*Average of 20 determinations throughout the growing season.
†Sodium nitrate and superphosphate, 16% P_2O_5.

The interrelationship of nitrogen and phosphorus appears noteworthy. It seems probable that increases of nitrate in the plant when phosphate fertilizers are used may be due to stimulation of bacterial action and nitrification. Although nitrate fertilizers do not influence the availability of phosphorus from the soil, the occurrence of increased nitrate in the plant probably stimulates the utilization of phosphorus. Thus, the phosphorus content in the conducting tissues would be found to be relatively low when the concentration of nitrate is high and relatively high if nitrogen is limiting growth. Despite variations due to utilization of phosphorus, it seems possible to deduce which element is limiting by making comparisons with the nitrogen-phosphorus concentrations found to accompany optimum production. Tests for both elements seem to be necessary before an interpretation can be made.

From data thus far obtained on nutrient levels in the plant at various stages of growth (detailed data are not presented here), it would seem that the optimum levels for high yields of tomatoes and lett would likely fall fairly close to the values given in Table 3 in p. of the enlarged portion next to the main stem of green lower petioles and lettuce midrib tissue at given stages of growth.

TABLE 2.—*Lettuce, average of two crops, in the greenhouse.**

Yield per plant, grams	Nutrients in the midribs		N ÷ P	Kind of soil	Sodium nitrate, tons per acre†
	Soluble N, p.p.m.	Phosphate P, grams			
89	848	131	6.5	Black loam	0.0
87	1,049	152	6.9	Black loam	0.1
86	937	167	5.6	Black loam	0.0
86	1,058	139	7.6	Black loam	0.0
66	844	54	15.6	Brown loam	0.1
62	1,021	46	22.2	Brown loam	0.2
60	662	74	8.9	Brown loam	0.0
55	619	44	14.1	Red clay	0.1
54	571	45	12.7	Brown loam	0.0
45	683	55	12.4	Sandy loam	0.1
42	755	18	41.9	Red clay	0.2
40	375	63	6.0	Red clay	0.0
35	394	88	4.5	Sandy loam	0.0
33	468	42	11.1	Sandy loam	0.0
32	872	29	30.1	Sandy loam	0.2
31	346	21	15.5	Red clay	0.0

*Average of six determinations for fall of 1933; eight for winter of 1933–34.
*Lettuce was grown on the tomato plats so that the treatments for tomatoes may have been still exerting an effect, especially phosphate.

TABLE 3.—*Favorable levels in the conductive tissue.*

Growth period	N of nitrate, p.p.m.	P of phosphate, p.p.m.	N/P
Tomatoes			
Early (about 12 inches high)	1,000–1,500	200–300	5
Medium (fruits set)	700–800	350–400	2
Late (fruits ripening)	300–350	300–350	1
Lettuce*			
Early (3–4 inches high)	1,500–2,000	150–200	10
Late (6–8 inches high)	800–1,000	100–125	8

*The results on nitrogen in lettuce are in p.p.m. of soluble nitrogen, not nitrate nitrogen.

PARTIAL CORRELATION COEFFICIENTS

In order to show the correlation between yield and the soluble nitrogen and phosphate phosphorus found in the mature conducting tissues of the plant, a statistical analysis was made using, Fisher[5] and Snedecor[6] as guides.

Several statistical values were determined, but only the partial correlation coefficients are presented since they best show the relation to yield. They have the advantage of showing the correlation between one factor and yield, the other factor being constant.

[5]FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 4. 1933.
[6]SNEDECOR, G. W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa: Collegiate Press. 1934.

All the data available at the time were used in computing these values and the number of determinations used is shown in Table 4. For instance, 640 determinations were used in the fall crop of tomatoes. This means that the 32 plats were sampled 10 times in duplicate. Four samplings were made in October ("early" column), four in November ("medium" column), and two in December ("late" column). The averages for each month were computed and were used in the correlation calculations. All long additions and multiplications were checked on a Marchant electric machine and a slide rule, Barlow's tables, and logarithms were used to check other calculations.

CORRELATIONS WITH YIELDS OF TOMATOES

Table 4 presents the partial correlation coefficients determined in the statistical analysis. The correlation of tomato yields with phosphate phosphorus is very high, gradually decreasing from 0.82 to 0.58 at the end of the crop. The lower correlation of 0.39 for the spring crop, early period, shows either that other factors were more important or that the experimental error was more in the small number of cases used. The correlation is significant, however.

It is regretted that other duties did not permit more determinations to be made. It is highly significant that the correlation with available nitrogen falls from 0.75 to 0.06 with the advent of the fruit setting period and continues low in the late stages. High amounts of nitrogen in the conducting tissues are not conducive to fruit set in tomatoes.

During the early period, when the drain on nutrients was very heavy in attaining plant size and nitrogen, as well as phosphorus, was needed in large amounts, an inverse correlation (— 0.49) between soluble nitrogen (nitrate nitrogen with tomatoes) and phosphate phosphorus was obtained, showing that as one element became limiting, the other tended to accumulate. This relation was not evident later in the fall crop, nor in the spring crop, since a partial correlation of 0.35 is required to be significant when $n = 29$ and using $P = .05$, according to Fisher's Table V.

CORRELATIONS WITH YIELDS OF LETTUCE

The partial correlation coefficients for lettuce do not run as high as with tomatoes. This is due, partly at least, to the difficulty in getting uniform samples of lettuce. The enlarged portion afforded a uniform sample next to the main stem of the lowest petiole of the tomato. In the case of lettuce, it was necessary to separate the midrib from leaf tissue. This gave a chance for some variation. Often the lowest leaf was small and several leaves were required, giving more chance for variation. However, most of the values are significant when yields are considered, soluble nitrogen especially giving several high coefficients.

In the fall crop, soluble nitrogen and yield gave 0.610 in the early period and dropped to 0.245 late in the growing period. Phosphate phosphorus rose from 0.486 early in the growth to 0.563 late in the season. In the winter crop, no samples were taken in the late period, but the middle period showed high coefficients, jumping from 0.565,

TABLE 4.—*Partial correlation coefficients between yield and soluble nitrogen and phosphate phosphorus found in the mature conducting tissues of the plant.**

Crop and season	No. of determinations	Yield and phosphate, soluble nitrogen constant			Yield and soluble nitrogen, phosphate constant			Soluble nitrogen and phosphate, yield constant		
		Early	Medium	Late	Early	Medium	Late	Early	Medium	Late
Tomatoes, fall, 1932†	640	0.824	0.724	0.583	0.751	0.062	0.200	—0.49	0.251	—0.053
Tomatoes, spring, 1933†	128	0.389	—	—	0.457	—	—	0.047	—	—
Lettuce, fall, 1933†	192	0.486	—	0.563	0.610	—	0.245	0.069	—	0.050
Lettuce, winter, 1933–34†	256	0.240	0.574	—	0.565	0.704	—	0.217	—0.230	—
Cucumbers, spring, 1934	160	0.418	0.265	0.085	0.318	0.441	—0.077	—0.472	—0.331	—0.247

*When n = 29, the correlation is significant at 0.35 (Fisher's Table V).
†Detailed data used in the calculations are presented in Kentucky Station Circular No. 43.

early, to 0.704 for soluble nitrogen, and from 0.24 to 0.574 for phosphate phosphorus. There was no significant relation between nitrogen and phosphorus in the lettuce results. It is apparent from this that it is important to keep both nitrogen and phosphorus high up to the late stages of growth. Maintaining high soluble nitrogen seems to be even more important for lettuce than high phosphate.

CORRELATIONS WITH YIELDS OF CUCUMBERS

The partial correlation coefficients for cucumbers were not so high as for tomatoes and lettuce. Probably two other factors contributed to the coefficients for which it was not possible to correct. First, the cucumber is especially affected by water relations, both in the soil and in the air. Although efforts were made to keep this factor uniform, the soils dried out so rapidly from the heavy growth of foliage that on the raised benches it was impossible to keep the soils from drying out unevenly. There were some variations in air humidity, also, in different sections of the house.

Second, the growing season was rather long and the latter part of the growth occurred in June and July when the temperatures were so high in the greenhouse as to prohibit normal growth. However, in the early growth stages, the coefficients are significant for phosphate and practically so for soluble nitrogen. In the medium growth stages, soluble nitrogen gave the highest coefficient of yield correlation (0.441). None of the coefficients are significant in the late, high-temperature period. It is interesting that there was a fair inverse correlation between phosphorus and nitrogen in both the early and medium growth periods. Contrary to what would be expected from the results with tomatoes, soluble nitrogen seems to be even more important than phosphate in setting cucumber fruits, while phosphate is important in gaining plant size in the early stages of both cucumbers and tomatoes.

RELATION OF PRECIPITATION TO MOISTURE STORAGE AND CROP YIELD[1]

A. F. BRACKEN AND P. V. CARDON[2]

IT is generally recognized that soil moisture with its various practical and fundamental relationships is the most important single factor connected with the profitable utilization of western dry-farm land. With a cropping system of alternate wheat and fallow, such as is necessary because of the distribution of the limited rainfall, the problem of successful wheat growing, so far as it can be controlled by the farmer, is one of moisture accumulation and conservation. The particular phase of the problem dealt with in this study is that of measuring the percentage of rainfall saved in the soil over a whole period of a fallow-crop cycle and fraction of a cycle as related to water cost of crop production. The results reported represent accumulated data from the Nephi Dry-Land Substation, Nephi, Utah, from 1909 to 1918 and from 1925 to 1933, both inclusive.

ENVIRONMENTAL FACTORS

Since soil type, altitude (5,300 feet), evaporation, temperature, wind, and total amount and distribution and precipitation are all definitely associated with the efficiency of rainfall in relation to yield, it is necessary to state measurements which have been made of these various factors. The soil is classed as a clay loam, reddish-brown in color, and uniformly 10 feet or more in depth with a nitrogen content of 0.1% in the surface foot. The average moisture equivalent to a depth of 6 feet is approximately 24%. Table 1 gives the average wind velocity, evaporation, and mean temperature for each of the seven months from April to October, inclusive, since 1908.

TABLE 1.—*Average wind velocity, evaporation, and mean temperature, April–October, 1908–1933, inclusive.*

	April	May	June	July	Aug.	Sept.	Oct.	Total
Wind, miles per hour	4.1	3.9	3.8	3.3	3.2	3.2	3.1	——
Evaporation, in.	3.898	6.545	8.730	9.547	8.733	6.367	3.532	47.352
Temperature, °F.	44°	53°	63°	71°	70°	61°	48°	——

The mean monthly and yearly average rainfall for the period since 1898 is given in Table 2.

[1]Contribution from Utah Agricultural Experiment Station, Logan, Utah. Publication authorized by Director, October 19, 1934. Received for publication October 26, 1934.

[2]Superintendent and Director, respectively, Nephi Dry-Land Substation. The writers acknowledge their indebtedness to F. D. Farrell, Kansas State Agricultural College, Manhattan, Kan.; A. D. Ellison, Belle Fourche, S. D.; and J. W. Jones, U. S. Dept. of Agriculture, Washington, D. C., all of whom, as superintendents of the Nephi Dry-Land Substation, directed and conducted the early work in this investigation. Credit is also due the following field foremen for their efforts in taking samples and in otherwise assisting in the work: Stephen R. Boswell, Nephi; James A. Eagar, now with the Plant Introduction Gardens of the Bureau of Plant Industry at Ship Rock, New Mexico; and the late I. J. Jensen of Moccasin, Mont.

TABLE 2.—*Average precipitation in inches, by months, 1898–1933, inclusive.*

Precipitation in inches												
Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1.09	1.19	1.53	1.33	1.56	0.57	0.84	0.93	0.91	1.15	0.90	1.02	13.05

METHODS

In this study, 12 1/10-acre plats, scattered at random over a part of the experimental field and serving as checks in various moisture experiments, were used. While six of the plats were in crop, the other six were in fallow. Tillage and seeding treatments were uniform for all plats. Moisture determinations were made by taking five samples from each plat to a depth of 6 feet with a King soil tube. The samples were then dried in a gas soil oven for a period of 12 hours at a temperature of approximately 110° C. Soil-moisture percentage was determined on the basis of the dry weight of soil.

RESULTS

RELATION OF PRECIPITATION TO MOISTURE STORAGE

Under an arrangement of alternate crop and fallow, for all practical purposes, conservation of moisture has a simple solution. It consists of merely plowing the land either in fall or early spring with only sufficient tillage given during the fallow period to control weeds. The percentage of rainfall which can be stored, however, even by following the best of tillage practices, varies greatly from season to season, as indicated by results given in Table 3. This table is divided into four parts, the first three of which represent definite fractions of a fallow-crop cycle. The first winter with plowing deferred until spring might be called the beginning of the fallow. In the fall of this period, moisture determinations were made and repeated again the following spring. The difference between the two represented the gain. Knowing the amount of precipitation between the two dates of sampling, the percentage of rainfall stored as soil moisture was calculated. The summer is commonly known as the season of summer fallow. Having moisture determinations for spring and fall, the percentage gain or loss was determined. The second winter of the cycle is that period during which another crop of winter wheat is starting growth. By taking soil samples in the spring of this period, the percentage of rainfall stored and the amount available to crop use were calculated for this fraction as well as for the whole fallow-crop cycle.

Table 3 is divided into two divisions, the first covering the period from 1909 to 1918 and the second from 1925 to 1933, each inclusive. For the first division, the tests were concerned only with soil moisture. Sampling was usually done about May 1 and again soon after removal of the crop—not later than September 15. For the second division, the study was conducted to determine the relationship between soil moisture and nitrate accumulation. The first samples for the latter were taken just as early as it was possible to get on to the land before the plants had used any appreciable amount of moisture,

except in seasons of fall emergence—in all cases not later than April 20. The last samples of the season were collected near November 1.

An examination of the data in Table 3 reveals the fact that apparently a larger percentage of precipitation was found in the upper 6 feet of soil after the first winter of the fallow-crop period than for any other fraction of the entire cycle. For the first division (1908–18), an average of 56.6% of the precipitation was conserved as soil moisture and for the second division (1925–33), 69.2%. This variation was due to the difference in time of taking samples, allowing a long winter period for the first and a shorter period for the second division of the study. On a sandy loam soil for a similar period, Widtsoe (10)[3] reported an average saving of 79.4% of the precipitation, with a range varying from 64.8 to 95.56%.

TABLE 3.—*Rainfall and percentage of rainfall saved in the soil over a whole period of a crop cycle and fraction of a crop cycle.*

Crop cycle	Rainfall in inches and precipitation in per cent conserved in soil over fallow-crop period							
	1st winter, land in stubble		Summer, fallow spring-plowed		2d winter, winter wheat fall-sown		Whole cycle	
	Amt., in.	Stored %	Amt., in.	Stored %	Amt., in.	Stored %	Amt., in.	Stored %
1909–1911......	8.03	22.2	2.88	10.0*	7.13	29.2	18.04	11.6
1910–1912	10.02	35.6	4.41	5.9*	6.48	65.2	20.91	31.8
1911–1913......	8.61	66.4	2.29	0.1	8.17	30.9	19.07	44.5
1912–1914......	9.11	65.6	3.92	10.9*	12.77	6.6	25.80	19.1
1913–1915......	13.08	54.0	4.22	14.8*	8.35	11.5	25.65	20.5
1914–1916......	8.96	69.7	4.70	0.1	9.20	20.3	22.86	36.0
1915–1917......	9.20	76.5	2.88	8.5*	6.52	32.5	18.60	41.0
1916–1918......	6.18	62.7	5.64	0.5*	7.44	41.4	19.26	32.1
Average......	9.15	56.6	3.88	6.1*	8.26	29.7	21.27	29.5
1925–1927......	5.55	73.1	4.04	26.1*	9.16	36.3	18.75	16.8
1926–1928......	9.16	49.4	3.49	16.8*	7.47	48.2	20.12	28.9
1927–1929......	7.47	76.6	4.10	12.6*	5.52	32.6	17.09	33.2
1928–1930......	6.52	75.0	8.92	0.3	6.17	49.4	21.61	28.4
1929–1931......	6.17	80.6	10.91	0.5	3.21	17.4	20.29	30.9
1930–1932......	3.21	46.0	2.93	7.7	6.72	71.4	12.86	39.5
1931–1933......	6.72	83.8	5.22	11.0*	3.65	60.7	15.59	39.7
Average......	6.40	69.2	5.66	10.5*	6.13	45.1	18.19	32.5

*Percentage of soil moisture lost during the summer fallow period not counting summer precipitation.

Correlation:

Rainfall (in.) to percentage rainfall stored over 1st winter after crop.. $r = -.214 - P < 0.1$

Rainfall (in.) to percentage rainfall stored over 2d winter of crop year.. $r = -.437 - P < 0.1$

Rainfall (in.) over whole period to percentage stored. $r = -.371 - P < 0.1$

[3]Figures in parenthesis refer to "Literature Cited," p. 20.

During the second winter the results show that an average of 29.7 and 45.1% of the precipitation, for the first and second sections, respectively, was available for plant use at the time samples were taken in the spring of the crop year. This difference likewise can be partly accounted for by there being a longer period between fall and spring sampling dates for the first division than was the case for the second part of the study. In addition, it is apparent that through later spring sampling a certain amount of soil moisture absorbed from rainfall would be used by the plants previous to making moisture determinations. When soil samples were gathered early in the fall, such as happened from 1909–11 to 1916–18, the same thing would also occur in seasons of early emergence of wheat stands. This happened in the falls of 1910, 1913, 1914, and 1916, which were in the crop cycles of 1909–11, 1912–14, 1913–15, and 1915–17, respectively.

In addition to this source of error, which partly accounts for the difference between the second winter periods of the first and second sections of the study, another error occurred which can be partly corrected. It will be observed that the low percentages of the second winter, beginning with 6.6 for the 1912–14 cycle, are grouped together in successive order over a period of high rainfall. From a detailed examination of moisture data covering the first winter, it has been found that water from rain and melting snow seldom penetrates the soil to a depth beyond 6 feet. For the second winter, especially during the seasons of higher precipitation such as occurred in the cycles of 1912–14, 1913–15, and 1914–16, increases in soil moisture for other tests with deeper sampling were measured down to 10 feet. Using these results as a basis for adjustment, 6.6% becomes 23%, 11.5 changes to 36, 20.3 increases to 32, and 36.2 is substituted for the average of 29.7%. If these same changes are carried through to the percentage of rainfall stored for the whole fallow-crop cycle, then 19.1, 20.5, and 36.0 become 27.3, 28.4 and 41.2%, respectively, with the average of 29.5% increasing to 32.2%. It is improbable from data available, depending upon intensity and distribution of rainfall, that any appreciable percentage of moisture moves down much below the 6-foot level when the total precipitation for the fallow-crop period amounts to 20 inches or less.

As previously indicated, the data in Table 3 show that a greater percentage of rainfall was conserved in the upper 6 feet of soil for the first winter than for either the summer period or the second winter of the fallow-crop cycle. In observing the rather marked variation between the first and second winters, it is clear that two different years are used. For example, the winter of 1909–10, the first winter of that particular cycle, is compared to the second winter of 1910–11 in the same cycle, and so on throughout the entire study. In order to make the comparison direct for the same season, the data for the last division of Table 3 have been rearranged and are given in Table 4. As shown by the averages, no significant change has been made in the results as compared to the arrangement given in Table 3.

The higher percentage of rainfall found in the upper 6 feet of soil at the end of the first winter as compared with that at the end of the second winter of the fallow-crop cycle is due to a number of factors. A

part of the difference, and a major part, especially in those seasons of early fall emergence of the crop, might be accounted for in the use of moisture by the growing plants. This occurred in the cycles of 1909–11, 1912–14, 1913–15, 1915–17, 1926–28, and 1929–31. As already explained, this likewise accounts for a part of the difference between the second winters of the first and second sections because of later spring sampling for the period from 1909–11 to 1916–18, inclusive. Movement of moisture to levels below 6 feet, the depth to which samples were taken, also offers an explanation for a part of the difference. This has already been mentioned in connection with the variation between the first and second sections.

TABLE 4.—*Percentage of precipitation stored in soil for stubble land and land fall seeded to winter wheat.*

Winter period	Rainfall, in.	Water stored	
		Stubble %	Crop %
1926–27	9.16	49.4	36.3
1927–28	7.47	76.6	48.2
1928–29	6.52	75.0	32.6
1929–30	6.17	80.6	49.4
1930–31	3.21	46.0	17.4
1931–32	6.72	83.8	71.4
Average	6.54	68.6	42.5

For the second winters of the 1911–13, 1916–18, 1925–27, 1927–29, 1928–30, and 1931–33 cycles, other factors, however, were likely responsible for most of the differences shown. In all of these seasons the crop failed to emerge before winter which precluded the possibility that the plants had used any great quantity of stored moisture before the samples were taken in the spring and, because of the lower amount of rainfall, no appreciable amount had moved much below 6 feet as indicated by samples taken 10 feet deep.

It has been observed that land in wheat after the snow leaves the ground is usually more compact than that in stubble, thus tending to favor a more rapid drying out of the surface, particularly, from a soil supporting plants not beyond the second and third leaf stage of growth. Associated with this condition, the stubble partly standing and partly lying down apparently seems to shade the ground more efficiently than untillered plants. It has also been noticed that a stubbled surface, associated usually with the characteristic looseness, serves as a more efficient barrier in uniformly preventing runoff of rapidly accumulating water from melting snow than a surface with plants just starting to develop. These latter factors, operating singly and in conjunction, are probably responsible for most of the variation between the first and second winter periods of the fallow-crop cycle, especially, as pointed out, when the plants are untillered up until the soil samples are gathered in the spring for moisture determinations.

Thus, it may be concluded, that the smaller percentage of rainfall found in the spring at the end of the second as compared to the first winter of the fallow-crop cycle in the upper 6 feet of soil was due to a

combination of factors, as follows: (a) Use of the stored water by the growing wheat limited mainly to seasons when stands emerge in early fall soon after seeding; (b) movement of moisture below the 6-foot level, especially in those seasons of high rainfall; (c) greater tendency for evaporation because of the condition of the surface; and (d) increased chances for loss by runoff, the last two limited principally to seasons when the crop is late in emerging.

After attempting to explain the difference in percentage of moisture saved in the soil between the first and second winters of a fallow-crop period, it is obvious that a significant loss occurred in excess of this variation. Despite the fact that runoff and evaporation are probably lessened by standing stubble and that moisture seldom moves below 6 feet in depth in the first winter of a fallow-crop cycle, an average of 56.6% of the rainfall, or 5.17 inches, was stored out of a total of 9.15 inches for the first period (1909–18) and 4.43 inches, amounting to 69.2%, was stored out of an average total amount of 6.40 inches for the second period.

This loss is likely limited mainly to two sources—runoff and evaporation. Runoff seldom happens on stubble land previous to spring plowing, although loss from this source occurs occasionally, especially in springs when the soil has been frozen to considerable depth previous to being covered with winter snow If the snow melts before frost leaves the ground, runoff becomes excessive. This was observed in the spring of 1919, which, however, is not included in this study. Rapidly melting snow, with water accumulating faster than can be absorbed by the soil, may be associated with loss by runoff, although any appreciable waste from this source is infrequent. The chief source of loss is probably due to evaporation.

In the South Plains region, Finnell (6) found that 65.8% of the rainfall evaporated from the surface during and immediately following precipitation. While these measurements were made in an area receiving the major portion of rainfall during the summer, and, therefore, can hardly be compared with measurement from the area under consideration, still the results show the importance of this source of loss. Very little evaporation occurs during the winter while the ground is covered with snow. Observations made elsewhere in Utah indicate that this source of loss amounts to less than 0.5 inch, extending from the latter part of November until about March 1. The greatest evaporation of moisture reserves for the winter period occurs in late fall and early spring, especially in the spring when the surface soil is saturated from melting snow and rain. It is not uncommon for this condition to continue from the time snow has melted until May 1, or thereabouts. It is observed from Table 1 that the evaporation for April from a free-water surface measures 3.898 inches. Fortier (7) reports an average weekly evaporation of 4.75 inches from a wet soil and 1.88 inches from a water surface under similar atmospheric conditions. This measurement was made when the mean air temperature in the shade registered 71° F. No data are available to show the comparative relationship of evaporation from a free-water surface and a saturated soil as influenced by a variation of temperature. The conclusion, however, might be drawn that for April, with a mean temper-

ature of 44° F, the evaporation from a saturated soil surface should equal or be slightly greater than that from free water. If the same ratio as exists between April and May can be applied to March and April, the evaporation for March from a free-water surface would measure 2.326 inches. This added to 3.898 inches for April equals 6.334 inches. It is not implied that this can be compared directly with what happens in the soil. The various relationships are far too complex with alternate freezing, thawing, and drying, changes in humidity, and clear and cloudy days, but the data, as well as inferences drawn from the results, lead to the conclusion that evaporation might be considered the major factor connected with losses of moisture during winter periods extending from the latter part of October to the latter part of April.

The summer rainfall of the Great Basin, amounting to approximately one-fourth of the total amount for the year, is ineffective in building up soil moisture reserves (Table 3). The summer storms usually occur either as light sprinkles of rain or as heavy torrential showers. The light rains are lost almost immediately by evaporation and the heavy showers fall so suddenly that at times a large portion runs off, carrying away some of the surface soil. Widtsoe (10) reports an observation made by Farrell in which 2.6 inches of rain fell in 4 hours. The surface of the fallowed land became so packed that only 0.25 inch, or less than one-tenth of the whole amount, soaked into the soil. Similar observations were made in 1929 and again in 1930, when the summer rainfall was far above the average (Table 3). When the surface is dry, a rain of 0.5 inch or less is of no value whatever in storing moisture, but in rainy periods when light showers come so close together that the surface soil is wet from one storm to another, even rains small in amount may penetrate below the surface. But it must be stated that, even though light showers fail to add anything to the soil moisture reserves, such storms are of value to growing crops and, to some extent, help to reduce evaporation from the soil.

On the Plains where the major part of the precipitation falls during the summer, Burr (3) found that 10 to 33% of the rainfall was saved over one winter and during the following summer up until time for seeding in the fall. Taking the same portion of the fallow-crop cycle from Table 3, an average of 33.8 and 26% of the rainfall for the respective 8- and 7-year periods was saved. Finnell (6) found that from 22 to 39% of the total rainfall of a wet period in the South Plains may enter the subsoil, with approximately 20% of the normal precipitation being saved for crop growth.

An examination of the detailed results for the summer period (Table 3) leads to the conclusion that no direct relationship exists between percentages of moisture lost or saved during the fallow period and amount of summer precipitation. It is the character of the storms which governs summer losses rather than the sum total. The summer rainfall in 1910 measured 2.88 inches, and without considering this 10.1% per cent of soil moisture which the soil contained in April of that spring was lost. The storms came as scattered showers with no storage. Similarly, the seasons of 1913, 1914, 1916, 1927, 1928, 1931, and 1932 were summer periods of scattered rains limited in amount.

For the fallow period of 1911, with 4.41 inches of rain, the storms were scattered but were of such a nature that loss from the soil was reduced to 5.9%. The seasons of 1915 and 1917 were of like character. The 2.29 inches of rain which fell in the summer of 1912 came in one or two heavy storms early in the season, thus entering the soil. For the fallow period of 1926, which was in the fallow-crop cycle of 1925–27, in the spring the soil contained an average of 17.6% moisture to a depth of 6 feet, while the fall sampling showed only 13%. After the late spring rains, amounting to 4.04 inches, summer and fall were seasons of protracted dryness and warmth.

The summer periods of 1929 and 1930 were epoch making in changing dry-land tillage for the Great Basin area. Previously, it was customary to level and harrow spring-plowed land soon after the plowing was finished, with additional harrowings during the summer. This left a smooth well-tilled surface. Under average summer conditions approximately 10% of the moisture contained in the soil at spring sampling time is lost by fall. If this is subtracted from the moisture percentages for 1929 and 1930, then it can be assumed that 19% and 20% of the 8.92 inches and 10.91 inches of precipitation for these two seasons, respectively, entered the soil to be stored for crop use. Part of the remaining portion was lost by evaporation, but because of the torrential character of the storms and because of the smoothness of the surface, a large percentage was lost by runoff, carrying with it a part of the soil, in places to the full depth of plowing.

A recent unpublished fertility survey of two typical dry-farm areas in Utah discloses the fact that approximately 20% of the nitrogen and organic matter reserves have been lost from the soil, part of this loss no doubt occurring from erosion. Since Harris and Jones (8) found that rough untilled spring-plowed fallow with weeds hoed off conserved as much moisture as did fallow which received normal tillage, and since Bracken and Stewart (1) report no difference in yield between plats similarly treated, farmers are now advised to let spring-plowed land lie rough and untilled until after the period of summer showers; however, weeding may be necessary. This practice not only saves labor and expense, but may also aid in conserving soil moisture as well as soil.

The correlations at the bottom of Table 3 show the relationship between rainfall and amount of precipitation stored in the soil. Because of there being only 15 years' results involved in this study, the individual correlations are not significant. Since all three are in the same direction, however, they do collectively indicate that the greater the rainfall, the less the proportionate amount stored.

From the foregoing discussion of results, the general conclusion might be drawn that precipitation is much more likely to increase soil moisture reserves when the weather is cool than during the summer when all of the dissipating forces are at the maximum.

RELATION OF PRECIPITATION TO CROP YIELD AND WATER COST OF CROP PRODUCTION

Yield of winter wheat on the dry lands of the Great Basin is a result of many factors, most important of which are distribution and

amount of precipitation. Early fall emergence of wheat stands is generally associated with high yields. This permits the development of a rooting system with a wide feeding range. Under such conditions plants produce most of their vegetative growth during the shorter and cooler days of the spring, maturing as dryness and warmth become more intense. If, on the other hand, vegetative development is forced into the hotter, dryer, and longer days of summer, through late winter or early spring emergence, it is usually at the sacrifice of yield. Late summer and early fall precipitation, therefore, is highly important to profitable dry-farm wheat production. The higher acre yields shown in Table 5, such as 30 bushels for 1911, 39.3 bushels for 1914, 31.1 bushels for 1915, 26.7 bushels for 1917, 25 bushels for 1928, and 23.9 bushels, are near the maximum when the seed fails to germinate before winter, and, according to the data in Table 5, acre yields ranged from this amount down to 6.8 bushels.

Wheat which is untilled on April 1 may suffer from a number of hazards which would otherwise not seriously affect well-developed stands. The plants may "crust under," as happened in the early spring of 1913. Low April temperatures, as unconducive to crop growth as to nitrate formation, may retard plant development. This occurred in 1927 and 1933. And drought, which usually becomes more acute with the advance of summer, can always be depended upon to reduce yields of late wheat. Chilcott (4) found that on the Great Plains where crop hazards are greater than in the area surrounding the Nephi Dry-Land Station, inhibiting factors to crop yield reduced production by approximately 48%. Using 30 bushels as an average maximum yield (as calculated from Table 5) and subtracting the averages from this figure, it might likewise be concluded that inhibiting factors reduced yields by 24 to 33%, respectively, for the first and second divisions of the study.

The correlations at the bottom of Table 3 also show that, in addition to total moisture and total rainfall, there are other factors which govern yield. It might be expected that the correlation of spring rainfall, covering the periods from April 1 to ripening time, should be higher and consequently more significant. The large yields of 1914, 1915, and 1917 were no doubt measurably increased by high spring rainfall, while the 30-bushel acre yield for 1911 was grown in a season of extremely low spring precipitation. It will also be observed that the low yields of 1918 and 1933 were produced in seasons of relatively high spring rainfall. The deficiency of a dry unproductive fallow associated with winter emergence of the crop cannot be remedied by high spring rainfall, yet it is recognized that without spring rain, late-maturing stands in certain seasons may result in partial failures.

In making an attempt to measure the water cost of dry matter and inches of moisture used for producing a bushel of wheat, it is realized from field studies that results cannot be exact because of the many factors involved which are beyond control. In spite of this fact, the calculations are helpful in interpreting some of the variations in production.

The water cost of dry matter, as shown in Table 5, was obtained by subtracting the amount of moisture remaining in the soil after harvest

TABLE 5.—*Total precipitation, total dry matter, water cost of dry matter, acre yields of wheat, and water cost of 1 bushel of wheat.*

Year	Total precipitation, in.	Total water, in.*	Water used by crop, in.			Total dry matter, lbs.	Water cost of dry matter, lbs.	Wheat yields, bu.	Acre inches water to 1 bu. wheat	No. bus. wheat to 1 in. water	
			Soil water	Spring rain†	Total					Soil water spring rainfall	Total water
1911	19.11	36.21	7.15	1.07	8.22	4,140	450	30.0	0.274	3.65	0.83
1912	22.16	26.56	7.36	1.25	8.61	1,852	1,053	14.7	0.586	1.70	0.57
1913	20.62	15.59	3.45	1.55	5.00	908	1,247	6.8	0.735	1.36	0.44
1914	29.40	32.32	5.78	3.59	9.37	5,230	406	39.3	0.238	4.20	1.22
1915	29.55	35.00	6.86	3.90	10.76	4,466	545	31.1	0.346	2.89	0.89
1916	24.11	22.01	6.23	1.25	7.48	2,119	800	17.5	0.427	2.34	0.80
1917	23.22	23.26	8.00	4.62	12.62	3,744	763	26.7	0.456	2.12	1.15
1918	22.04	23.13	7.28	2.76	10.04	1,979	1,149	15.7	0.639	1.56	0.68
Average	23.77	26.76	6.15	2.50	9.01	3,055	801	22.8	0.463	2.47	0.82
1927	20.24	30.24	6.37	1.49	7.86	2,210	805	16.0	0.468	2.13	0.53
1928	22.21	22.21	5.81	2.09	7.90	3,208	558	25.0	0.316	3.16	1.13
1929	19.70	20.50	5.00	1.61	6.61	2,690	556	20.3	0.334	2.99	0.99
1930	25.25	22.45	5.72	3.64	9.36	2,770	765	20.8	0.450	2.22	0.93
1931	21.06	21.15	6.55	0.77	7.32	3,700	448	23.9	0.306	3.26	1.13
1932	15.41	17.44	7.10	2.55	9.65	3,720	588	19.2	0.530	1.88	1.10
1933	19.97	22.25	6.92	4.38	11.30	2,080	1,231	15.9	0.711	1.40	0.71
Average	20.55	22.32	6.21	2.36	8.57	2,911	709	20.2	0.445	2.43	0.93

*Total water over fallow-crop cycle, including spring rainfall with correction for moisture reserves used from previous cycle and amounts remaining for crop use after harvest.
†Rain (in.) coming after soil was sampled up until ripening of crop.

Correlation:

Total water to acre-yield . . . . $r = .629$—$P = 0.01$
Total rainfall to acre-yield . . . . $r = .561$—$P = 0.02$
Spring rainfall to acre-yield . . . . $r = .394$—$P < 0.1$

to a depth of 6 feet from that found in the spring. This amount was then added to the rainfall (inches) which fell from the time of sampling to the beginning of ripening. The total pounds of dry matter were then divided into the total amount of water used. The acre inches of water used to produce a bushel of wheat and the bushels of wheat grown by each inch of soil water were similarly calculated. It is understood that in adding spring rainfall to the cost of crop production that storms too limited to reach the roots have been included. Light showers are of value, however, in that the atmosphere is cooled off, humidity is increased, and transpiration is decreased, thus making stored soil moisture more efficient in expressing itself in crop yield. The figures in the last column of Table 5 (bushels of wheat to each inch of total water) were obtained by using the total moisture as a basis. This includes total precipitation over the whole fallow-crop cycle with corrections for after harvest. Precipitation falling from time of spring sampling to beginning of ripening was added to this amount. The total was then divided into the acre yields of wheat.

The data given in Table 5 seem to point to the fact that the water cost of dry matter per unit quantity of water used and also acre inches of water to each bushel of wheat tend to decrease with the yield for the range of the moisture involved. The low acre yield of 6.8 bushels for 1913 was associated with the highest water cost of dry matter (1,247 pounds). This was followed by the highest yield shown in Table 5, *viz.*, 39.3 bushels, with 406 pounds as the water cost of dry matter, which was the lowest recorded.

The variety Turkey Red winter wheat (C. I. No. 2998) was grown during the first 8 years of this study and Utah Kanred was used during the second period. Briggs and Shantz (2), in a carefully controlled experiment at Akron, Colo., found the average water cost of dry matter to be 473.8 and 475.8 pounds, respectively, for Turkey C. I. No. 1571 and Kharkov C. I. 1583. It will be observed from Table 5 that, in seasons of high yield, the water cost of dry matter approximated the amounts found by these two investigators.

Hopkins (9), working at Swift Current, Saskatchewan, Canada, gave 489 pounds as the water cost of a pound of dry matter when wheat was grown on fallow lands and 764 pounds when wheat followed wheat.

Cole and Mathews (5) made a similar study with spring wheat, taking results from 18 Plains dry-land stations. The figures varied from 382 pounds with an acre yield of 56.5 bushels at Belle Fourche, S. D., to 3,208 pounds with an acre yield of 1.5 bushels at Assiniboine, Mont. At Edgeley, N. D., a 10-year average showed the water cost of dry matter to be 1,047 pounds. At North Platte, Neb., for a 9-year period the water cost was 980 pounds. In a 6-year test in Utah, Widtsoe (10) found that when wheat was supplied with sufficient water for normal growth, 1,048 pounds of water were required to produce a pound of dry matter.

Thus, it is evident that the cost of crop production in terms of water varies greatly. Most of the results within the limits of this experiment, i. e., on dry-farm lands show that high yields are usually associated with a low water cost, while low yields accompany a high water cost of

dry matter. At the Nephi Dry-Land Station a low water cost of dry matter is always associated with a productive fallow and early fall emergence of the crop. On the other hand, an unproductive fallow and late emergence of wheat stands, when rated in terms of water, are expensive.

The last two columns in Table 5 give the bushels of wheat produced by each inch of soil water plus spring rainfall and by each inch of rainfall when total moisture in inches is added to spring rainfall of the crop year. The figures for individual years show some variation, but, generally speaking, seasons of high yield are associated with high production per unit of water whether it be soil moisture plus spring rainfall or total rainfall. In the season of 1914, with a production of 39.3 bushels to an acre, each inch of soil water grew 4.2 bushels of wheat; for 1911, with an acre yield of 30 bushels, 3.65 bushels; and for 1928, with an acre yield of 25 bushels, 3.16 bushels were produced by each inch of soil water. In almost every case the seasons of low yield were associated with low production per inch of soil water plus spring rainfall. Widtsoe (10) calculated that each inch of soil water should produce 2.5 bushels of wheat. The averages of 2.47 and 2.43 bushels for each inch of soil water, respectively, for the first and second periods (Table 5) approximate this figure. Chilcott (4), in averaging results from all the Plains dry-land stations, found the ratio of yield to rainfall to be 0.981. Calculated in the same manner, the ratio for the first division of Table 5 was found to be 0.962 and for the second 0.983. When a correction was made to the rainfall for moisture reserves used from the previous crop cycle and amounts remaining for crop use after harvest, the ratios are 0.82 for the first and 0.93 for the second parts of this table.

SUMMARY

Because of the low rainfall in the Great Basin, with 75% falling during the fall, winter, and early spring months, a cropping arrangement of alternate wheat and fallow has come to be regularly practised on dry-farms.

From late October to the middle of April, 69.2% of the precipitation for the first winter and 45.1% for the second winter was conserved as soil moisture. Use of moisture by the growing crop, movement of water to depths beyond 6 feet, increased evaporation, and greater tendency for runoff have all contributed to differences between the first and second winters of a fallow-crop cycle. In addition to the variation between the first and second winters, a loss of approximately 30% occurred, due mainly to evaporation and occasionally runoff.

During the summer-fallow period rains seldom make any significant addition to the stored soil moisture.

Over a whole fallow-crop cycle approximately 30% of the precipitation was conserved.

High yields of dry-farm winter wheat in the Great Basin are directly associated with fall emergence. When plants fail to emerge before winter or early spring, the maximum yield is usually not more than 20 bushels. Late crops suffer greater hazards than earlier matur-

ing stands. The deficiency of late emergence usually cannot be remedied by high spring rainfall.

The water cost of dry matter and also the acre inches of water used in producing a bushel of wheat seemed to decrease with yield within the limits of the range of moisture involved. Taking an average of both divisions of the study, 756 pounds of water were used to produce a pound of dry matter, 0.454 acre inch of water was used to produce a bushel of wheat; 2.45 bushels of wheat were produced by each inch of soil water plus spring rainfall; and 0.87 bushel was grown by each inch of total water.

When acre yield of wheat was correlated with precipitation, it was found that the highest and most significant was with total water available followed by total rainfall. While the correlation of spring rainfall to yield was not high enough to be significant, it is recognized that without spring rain late-maturing stands in certain seasons may result in partial failure.

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A VERY RAPID AND EASY METHOD OF TESTING THE RELIABILITY OF AN AVERAGE AND A DISCUSSION OF THE NORMAL AND BINOMIAL METHODS[1]

S. R. MILES[2]

STATISTICAL methods, when used properly and with discrimination, are an invaluable tool in research, but statistical results are sometimes difficult to comprehend and the methods are often tedious to use. In a previous paper, the writer (2)[3] made a plea for the use of more easily understood methods of *stating* the reliability of the results of a research, and presented a table of odds to aid in attaining that objective. In the present paper a short method is presented for very rapidly and easily *determining* how much confidence can be placed in a particular average. In addition, the two common methods of determining the significance of an average are discussed and compared.

The tests of significance discussed in this paper may be used for a median, an ordinary mean (arithmetic average), a mean of differences secured by the pairing of values, a difference between two means when pairing is not done, or the more likely of two alternatives.

Although considerable knowledge of statistics is necessary for the reader to understand all the discussion which precedes the explanation of the use of the short method, most anyone can understand the little necessary to make accurate use of this method.

It is well to emphasize that in research certain things must be assumed and that if these assumptions are seriously in error, the conclusions may be wrong. This fact is too often forgotten. The first necessary assumption to be emphasized is that the sample with which the investigator works is truly representative of the larger population concerning which he wishes to generalize. Too much thought cannot be devoted to planning a research problem so that this assumption will be a fact. Tests of significance (reliability), too, are based on certain assumptions which will be discussed later.

THE NORMAL AND BINOMIAL METHODS

There are two commonly used methods of testing significance. The first, which we will call the *normal method*, is based on the normal distribution of individual values in an infinite population. The second, the *binomial method*, is based on the distributions of "successes" and "failures" when a "success" and a "failure" are equally likely. These distributions result from expanding the binomial $(\frac{1}{2} + \frac{1}{2})^n$ for any value of n.

Heretofore, the normal method has been used by calculating the root-mean-square deviation (standard deviation) and a t value and

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[3]Numbers in parenthesis refer to "Literature Cited," p. 31.

then finding the significance from a table. This procedure has been explained in detail by Student (4, 5), Fisher (1), the writer (2), and others. This particular procedure, which is much the most common for finding significance, is one way of applying the normal method and will hereafter be called the *usual normal method*. A second way of applying the normal method is one phase of the *short method* described in this paper.

The binomial method also is used to a considerable extent, but it could well be used a great deal more. Its use in agronomic work is largely due to Salmon (3), who showed how it can be applied in agronomy when values are paired. Pairing is not necessary, as will be shown in examples 4 and 5 of the use of the short method, and the binomial method may be used in all fields of research work.

The exactly correct binomial odds are obtained from the distribution which results from expanding the binomial $(\frac{1}{2} + \frac{1}{2})^n$. This binomial has been expanded by the writer for each value of n to 25. The results were used in preparing the tables and figures. Because of the difficulty of expanding the binomial, it is almost universal to obtain the *approximate* binomial odds by calculating the standard error and the deviation from the expected number of occurrences.

The best formula for computing the deviation from the expected in the case of the binomial method is

$$d = m - \tfrac{1}{2}n - \tfrac{1}{2}, \qquad (1)$$

when d is the deviation, m is the number of values which are larger (or smaller) than any selected value, and n is the total number of values in the sample. Also, n may be the number of trials and m the number of those trials which gave one of only two possible alternative results. The formula for the standard error is

$$S = \tfrac{1}{2}\sqrt{n}. \qquad (2)$$

To determine the significance of the deviation, also calculate t from the formula $t = d/S$. (3)

The significance of the deviation may be found by looking up the value of t in Miles' (2) table of odds, or in Student's (5) or Fisher's (1) tables of probability, using the column or row for an infinite number of degrees of freedom. If $t = 1.65$, the odds are 19: 1, and if $t = 2.33$, the odds are 99: 1, when a difference is being tested. If Fisher's table is used, the probability given at the head of the column should be divided by 2 to find the probability *against* the true value of the average being larger (or smaller) than the selected value. This is when a difference is being tested.

The procedure which has just been given may be called the *usual binomial method* and is one way of applying the binomial method. A second way of applying it is the second phase of the *short method* to be described.

In explaining the use of the usual binomial method, Salmon (3) worked with the probable error, whereas the standard error is somewhat preferable. More important, he did not include the last term of equation 1.

The need for the final term may be explained by the aid of Fig. 1. If a perfect coin is tossed, the head or the tail is equally likely to show.

Fig. 1 illustrates that if four perfect coins are tossed a great many times, we will expect to have on the average from 16 tosses no heads one time, one head four times, two heads six times, three heads four times, and four heads one time. Thus, because in 16 tosses three or four heads are expected five times, the odds are 11:5 (or 2.2 : 1) against securing three or more heads in one toss of four coins. Geometrically, the odds are found by dividing the polygon of Fig. 1 into two parts by the line AB which separates the rectangles representing the frequency of occurrence of three or more heads from the rest of the polygon. The ratio of the larger part of the polygon to the smaller part is the odds.

Equation 1 is used to find how far the division line should be from the center of the base of the polygon. For Fig. 1, m is 3 and n is 4 and the use of equation 1 gives $\frac{1}{2}$ as the correct distance of the division line AB from the center. If the final term of equation 1 were omitted, the distance of the division line from the center would be indicated as 1.0 and the line would fall at C3. This division would give odds of 13: 3 (or 4.3: 1), which are too high. A similar argument for the final term would apply for all values of m and n.

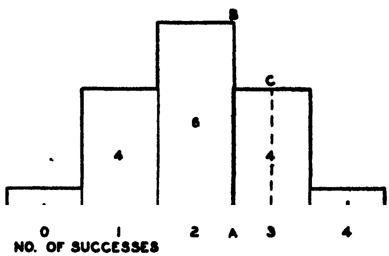

Fig. 1.—Polygon showing the relative expected frequency of occurrence of 0, 1, 2, 3, and 4 successes (or failures) in a large number of experiments of four trials each when a success or a failure is equally likely to occur at each trial. From $(\frac{1}{2}+\frac{1}{2})^n$.

Table 1 shows that the use of equation 1 gives a very satisfactory estimate of the true binomial odds, but that if the last term is omitted the estimate is seriously high.

TABLE 1.—*A comparison of the true binomial odds with estimates made by using two formulas.*

True odds	n*	Odds estimated by the two formulas	
		$d = m - \frac{1}{2}n - \frac{1}{2}$*	$d = m - \frac{1}{2}n$*
19:1	7	17.8	40
	10	18.0	37
	25	18.6	29
	50	18.6	26
99:1	7	71	197
	10	75	185
	25	90	155
	50	94	138

*See the text for the meaning of the symbols and for the discussion of the equations.

NORMAL AND BINOMIAL METHODS COMPARED

Let us now compare the normal with the binomial method. The binomial method is based on only one assumption, namely, that the chances are equal for obtaining values on each of the two sides

of the true mean value. In contrast, when the normal method is used, three things are tacitly assumed. The first assumption is the same as for the binomial method; the second is that the values in the population sampled are distributed normally; and the third is that the estimate of the standard deviation made from the sample is correct for the population. As a rule, the assumption for the binomial method can be approximated closely in reality by carefully planning and executing the piece of research. Usually, however, considerable doubt must remain as to whether the last two assumptions for the normal method hold even reasonably well. An advantage of the binomial method is that it is based on only the one rather easily satisfied assumption.

The binomial method indicates lower significance (odds or probability) than the normal method when the distribution of the values *of the sample* is exactly normal. This is demonstrated as follows.

In the case of the usual normal method, let σ be the standard deviation of individual values, S the standard error of the mean[4], n the number of values in the sample, and d the deviation of the mean of the sample from any value which may be selected against which to test this mean. Since

$$S = \sigma/\sqrt{n}, \qquad (4)$$

therefore, $$tS = t\sigma/\sqrt{n}. \qquad (5)$$

By definition—equation 3— $$t = d/S,$$

therefore, $$d = tS. \qquad (6)$$

Substituting in equation 5 $$d = t\sigma/\sqrt{n}. \qquad (7)$$

Next, decide on any normal odds, say 99: 1, for which the corresponding binomial odds are to be found for any value of n, say 100. In Miles' (2) table of odds in the column for an infinite number of degrees of freedom, find (odds of) 99, and to the left find the corresponding t value, which is 2.33. In equation 7 substitute 2.33 for t and 100 for n. Solving, gives $d = 0.233\sigma$.

Now if we select a value 0.233σ smaller (or larger) than the mean of the sample, the normal odds are 99: 1 that the true mean is larger (or smaller) than this selected value. A table of the probability integral shows that 59.2% of the values in a normal distribution lie to one side of a point 0.233σ from the mean, which is the selected point. For the problem at hand, this would be 59.2 values. Taking n as 100 and m as 59.2 and applying the usual binomial method, the binomial odds are found to be 23.6: 1. These correspond to normal odds of 99: 1. Reversing this procedure will give the normal odds corresponding to selected binomial odds.

Table 2 summarizes the results of repeated calculations for various odds and various values of n and shows that binomial odds are much lower than normal odds when the values *of the sample* are normally distributed. In practice, Student's odds should be used when n is 21

[4]The same symbol, S, is used both here in the discussion of the usual normal method and in the earlier discussion of the binomial method because in each case it represents the standard error appropriate to the method being discussed. The use of a single symbol makes possible the general formula $t = d/S$ which indicates that t is found by dividing any deviation (d) which it is desired to test for significance by the appropriate standard error, S.

or less. The table shows that the difference between Student's and binomial odds is not nearly so great as between normal and binomial odds. Also, in an empirical study[5] with over 90 sets of data from several fields of work, the writer found that in a great majority of the cases the usual normal method gave higher (normal or Student's) odds than the binomial method.

TABLE 2.—*A comparison of binomial odds with normal odds and with Student's odds when the values of the sample are distributed normally.*

Normal odds	Binomial odds for various values of n*						
	n = 5	6	10	20	35	100	1000
19:1.....	3.4	3.8	4.8	5.8	6.7	7.8	9.1
99:1.....	6.6	7.7	11.1	15.5	19.0	23.6	26.8
Binomial odds	**Normal and Student's odds for various values of n***						
	n = 5	6	10	20	35	100	1000
19:1.....	13,000 (103)†	1,650 (86)	317 (85)	145 (83)	99	71	50
99:1.....	‡	‡	55,000 (787)	3,500 (730)	2,150	1,000	660

*n is the number of values in the sample.
†Numbers in parenthesis are Student's odds from Miles' (2) table.
‡Binomial odds as high as 99:1 are not possible with samples of 5 or 6.

Salmon (3) made two comparisons in which the two methods gave identical results. However, this was due to chance alone and indicates that the distributions of the sample values were not normal. In 18 of the 22 comparisons which he made, the binomial method indicated lower significance. Had he used equation 1, this method would have given lower significance in 20 of the 22 cases. This being true, the binomial odds are 16,512: 1 that the binomial method should give lower odds than the normal method.

Because the binomial curve is very nearly normal even for moderate values of n, many persons believe that the normal and binomial methods should give nearly the same odds. This should not be expected upon further thought. The two normal distributions are of entirely different things. For the normal method, it is frequencies of individual values, such as bushels, inches, etc., which are normally distributed, while, for the binomial method, it is frequencies of all possible combinations of the two alternatives. The combinations of the alternatives vary from all of the first and none of the second alternative to none of the first and all of the second. Another striking contrast is that for the normal method m and n are *areas* under the curve, whereas for the binomial they are *points* on the base line of the curve.

It can be shown that when the binomial method gives higher odds than the *usual normal method*, the distribution is so far from normal

[5]The writer is indebted to the following men for part of the data used in the empirical study: Dr. R. M. Caldwell, S. F. Thornton, J. F. Trost, M. O. Pence, and K. E. Beeson.

that the use of the latter is not valid. Thus, the binomial method is the better even when it gives the higher odds.

Another advantage of the binomial method is that it cannot give high odds with very small samples, whereas the *usual normal method* can give infinite odds even with samples of two. It is risky to place much confidence in very small samples.

The normal method will give odds greatly in error for badly skewed distributions. The binomial method, however, is properly used even in such cases.

The normal method always tests the mean, whereas the binomial method always tests the median. (The median is a value larger than half the values and smaller than the other half.) In symmetrical distributions, the median and the mean coincide and in such cases the binomial method tests both. Throughout this paper reference is made to tests of the mean, but when the mean and the median do not coincide it should be remembered that the binomial method tests the latter.

The binomial method cannot lead to one kind of serious error to which the *usual* normal method may lead if used blindly. The latter may indicate that a certain mean is significant even when that constant does not represent the data at all well because the sample is very badly skewed. In several of the 90 cases which were used in the empirical study previously mentioned, it was found that the mean represented the data very poorly because it had a sign opposite that of the majority of the values. The *usual* normal method does not reveal such a fact, but the binomial or the short method will do so when correctly used. In one case the *usual* normal method gave the significant odds of 34 : 1 that the true mean had a negative sign, although a majority of the signs in the sample were positive. The binomial odds were 2 : 1 that most of the signs were also positive in the population represented by the sample. Neither the usual binomial method nor the short method for either normal or binomial odds can lead to such an error in judging the significance of a mean as resulted from the use of the *usual* normal method in this case.

Faulty technic and errors of various kinds produce data containing erroneous values. Such values have no effect upon the odds secured by the binomial method unless one or more values are changed from one side to the other of the value selected to be tested as the true mean. With the *usual* normal method, on the other hand, every value is used in computing both the mean and the standard deviation, and, as a consequence, erroneous values are almost certain to affect the odds.

The *usual binomial method* is much easier to use and much more rapid because it requires less calculation than the *usual normal method*. In fact, the calculations for the former can often be performed mentally with sufficient accuracy when the odds are definitely significant. By convention, odds of 19 : 1 are generally considered significant. Therefore, when a difference is being tested, a t value (see equation 3) greater than 1.65 may be taken to indicate significance.

The one disadvantage of the binomial method is that it gives odds which are too low or unnecessarily conservative when all three assumptions hold on which the normal method is based.

KIND OF ODDS TO USE

The comparison of the two methods leads to the question as to which is correct. The answer is that each is correct for the assumptions on which it is based. The comparison shows that the binomial odds are safe. This is because any well-planned and well-conducted research should closely meet the one assumption for the binomial method. The writer has been unable to think of any possible data from careful research to which this method could not be applied with confidence if the facts in the italicized paragraph above are kept in mind.

On the other hand, the normal method not infrequently gives results seriously in error because all three conditions on which it is predicated do not obtain. It is not safe, therefore, to use this method blindly, as is so commonly done.

What then is the practical thing to do in deciding which kind of odds to use? The binomial odds should be found first because they are safe and because they are easier to find when the table or graphs for the short method are not at hand. If the binomial odds are significant, there is no object in going farther. If these odds are low, the normal odds may then be found if the worker is anxious to show significance. Then if the normal odds are significant, the shape of the distribution of the values in the sample should be investigated. Generally, confidence should be placed in the normal odds only if the distribution is nearly normal. Occasionally, as in example 5 below, conditions are such that an experienced person may confidently use normal odds without testing the distribution

It is well to state the kind of odds reported, and *the use of normal odds should be justified when their use is necessary to show significance.*

THE SHORT METHOD

The short method can be used to find either normal or binomial odds, and it is much faster and easier than either usual method. This method gives binomial odds which are always correct and normal odds which are the same or approximately the same as are given by the usual normal method when the distribution of the values *in the sample* is normal or approximately so.

Briefly, the short method is used by counting the total number of values in the sample and also the number larger (or smaller) than any selected value. Table 3 or Fig. 2 or 3 is then used to find the odds that the true value of the average being tested is larger (or smaller) than the selected value.

Table 3 gives the correct binomial odds for values of n from 2 to 25. In Figs. 2 and 3 curves are used to indicate the odds. Fig. 2 is used when n is 30 or less, while Fig. 3 is used when n exceeds 30. For points on curve A, the *normal* odds are 19: 1; for curve B the *binomial* odds are 19: 1 and the *normal* odds are high; for curve C the *binomial* odds are 99: 1 and the *normal* odds are very high. The lower half of Table 2, which shows the normal odds corresponding to binomial odds of 19: 1 and 99: 1 for various values of n, shows more definitely the normal odds represented by various points on curves B and C. Most persons will do well to be conservatively safe by using only curves B and C for odds of 19: 1 and 99: 1, respectively.

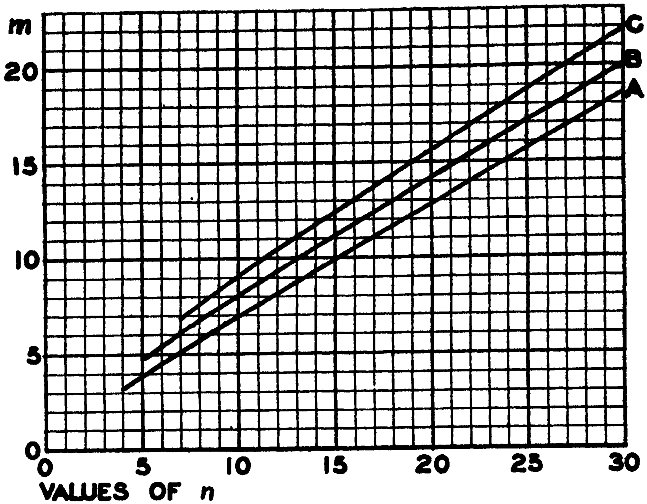

FIG. 2.—Curves of binomial and normal odds for values of n to 30. n, number of values in the sample or number of trials; m, number of values larger (or smaller) than any selected value or number of successes (or failures).

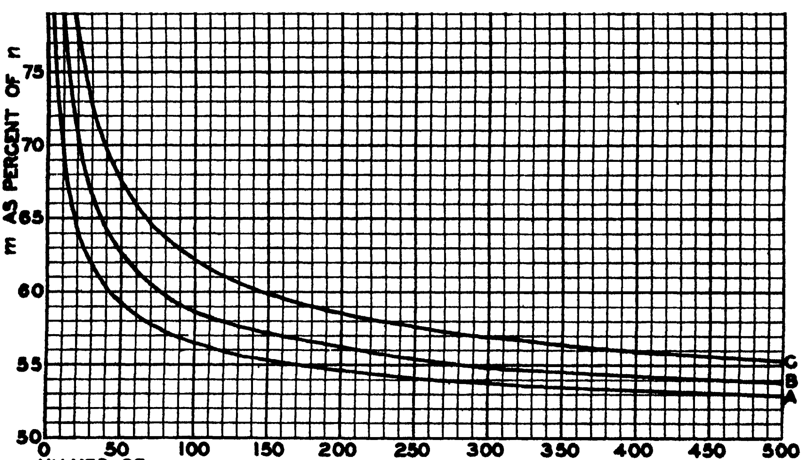

FIG. 3.—Curves of binomial and normal odds for values of n to 500. n, number of values in the sample or number of trials; m, number of values larger (or smaller) than any selected value or number of successes (or failures).

The odds shown by Figs. 2 and 3.

Curve	Kind of odds	
	Binomial	Normal
A........................	Low	19:1
B........................	19:1	High
C........................	99:1	Very high

TABLE 3.—*Odds against the occurrence of m or more like results, purely by chance, in n trials, from two alternatives which are equally likely to occur, for values of n from 2 to 25.**

m	n=2	3	4	5	6	7	8	9	10	11	12	13
2	3.0	1.0	—	—	—	—	—	—	—	—	—	—
3	—	7.0	2.2	1.0	—	—	—	—	—	—	—	—
4	—	—	15.0	4.3	1.9	1.0	—	—	—	—	—	—
5	—	—	—	31.0	8.1	3.4	1.7	1.0	—	—	—	—
6	—	—	—	—	63.0	15.0	5.9	2.9	1.6	1.0	—	—
7	—	—	—	—	—	127	27.4	10.1	4.8	2.6	1.6	1.0
8	—	—	—	—	—	—	255	50.2	17.3	7.8	4.1	2.4
9	—	—	—	—	—	—	—	511	92.2	29.6	12.7	6.5
10	—	—	—	—	—	—	—	—	1,023	170	50.8	20.7
11	—	—	—	—	—	—	—	—	—	2,047	314	88.0
12	—	—	—	—	—	—	—	—	—	—	4,095	584
13	—	—	—	—	—	—	—	—	—	—	—	8,191

m	n = 14	15	16	17	18	19	20
8	1.5	1.0	—	—	—	—	—
9	3.7	2.3	1.5	1.0	—	—	—
10	10.1	5.6	3.4	2.2	1.4	1.0	—
11	33.8	15.9	8.5	5.0	3.1	2.1	1.4
12	153	55.9	25.0	12.9	7.4	4.6	3.0
13	1,091	270	93.0	39.8	19.8	11.0	6.6
14	16,383	2,047	477	156	63.7	30.5	16.3
15	—	32,767	3,854	850	264	103	47.3
16	—	—	65,535	7,281	1,523	451	168
17	—	—	—	131,071	13,796	2,744	775
18	—	—	—	—	262,143	26,213	4,969
19	—	—	—	—	—	524,287	49,931
20	—	—	—	—	—	—	1,048,575

m	n = 21	22	23	24	25
11	1.0	—	—	—	—
12	2.0	1.4	1.0	—	—
13	4.2	2.8	1.9	1.4	1.0
14	9.5	6.0	3.9	2.7	1.9
15	24.5	13.9	8.5	5.5	3.7
16	74.2	37.1	20.5	12.2	7.7
17	277	117	56.7	30.3	17.5
18	1,342	459	187	87.3	45.2
19	9,038	2,337	768	302	135
20	95,324	16,512	4,095	1,292	490
21	2,097,151	182,360	30,283	7,220	2,196
22	—	4,194,303	349,524	55,700	12,777
23	—	—	8,388,607	671,000	102,927
24	—	—	—	16,777,215	1,290,554
25	—	—	—	—	33,554,431

*From the binomial $(\frac{1}{2}+\frac{1}{2})^n$.

Some examples of the use of the short method follow. The first three are different kinds of tests when pairing has been done.

Example 1.—E and F were compared in 25 pairs. In 20 pairs the value of E exceeded that of F. In Fig. 2 it is found that the point mn, the intersection of vertical line 25 (for n) and horizontal line 20 (for m), is above curve C. The binomial odds are therefore greater than 99: 1 that the mean of E really exceeds that of F. Table 3, in the column for $n = 25$ and on the line for $m = 20$, gives the exact binomial odds as 490: 1. The values of E and F may have been expressed as bushels, feet, cubic inches, or any other unit of measure.

Example 2.—In the sample of example 1, 18 values of E exceeded the corresponding values of F by more than 2.5. Because the point mn for $n = 25$ and $m = 18$ is between curves B and C, the binomial odds are between 19: 1 and 99: 1 that the true mean of E exceeds that of F by at least 2.5. Table 3 gives the exact binomial odds as 45.2: 1.

Example 3.—G and H were compared in 30 pairs. G exceeded H 27 times. For how large a difference are the binomial odds 19: 1? The (vertical) line for $n = 30$ intersects curve B of Fig. 2 on the (horizontal) line for $m = 20$. Therefore, m must be 20 for odds of 19: 1. Arrange the amounts by which G exceeded H in order of size. Count from the largest to the 20th in size, which we will suppose is 4.0. Then the binomial odds are 19: 1 that G really exceeds H by at least 4.0.

Ties are rather common when values are paired. In some cases it is proper to divide the ties equally between the two alternative classes, but in other cases the ties must be omitted. It is suggested that ties always be omitted in counting both m and n when the test being made is that the true mean difference is greater (or less) than zero, which was the test made in example 1. When ties are omitted, the odds found are the odds that *when there is a difference* the true mean difference is greater (or less) than zero. For tests such as were made in examples 2 and 3, the ties should be included.

When pairing is not logical, the test of the significance of a difference between two means is made somewhat differently. It can be shown that when two distributions are about normal, when both means have the same standard error, and when the normal odds are exactly 99: 1 that the *true* value of each mean differs from the *estimated* value of the other mean, then the normal odds are exactly 19: 1 that the *true* value of the larger *estimated* mean is larger than the *true* value of the other mean. Therefore, if both points mn found in testing each mean against the other are on or above curve B, the normal odds are very likely at least 19: 1 that the two means are really different. Also, if one point mn is only slightly below curve B and the other point mn is well above curve B, the normal odds are very likely at least 19: 1 that the true means are different. It is probably correct to use the same procedure for binomial odds by using curve C instead of B, though this has not been proved. The next example illustrates the use of the short method when pairing is not possible. This test should be made only if the values of n in the two samples are not greatly different.

Example 4.—A sample of 28 men from race P had a mean height of 60 inches and a sample of 21 men from race Q had a mean height of 65 inches. Nineteen men of race P were shorter than 65 inches and 15 men of race Q were taller than 60 inches. In Fig. 2, point mn for P, with $n = 28$ and $m = 19$, is slightly above curve B. Point mn for Q, with $n = 21$ and $m = 15$, is also above curve B. Therefore, the normal odds are very probably at least 19: 1 that the men of race P really average shorter than the men of race Q.

The next example tests an ordinary mean to see whether its true value is smaller than a selected value.

Example 5.—Suppose that extensive research has shown that the true average height of men of race J is 66 inches. In a random sample of 400 men of race K, 216 were shorter than 66 inches. What are the odds that the true mean height of men of race K is less than that for men of race J? Fig. 3 must be used because the sample is larger than 30. For using Fig. 3, m must be expressed as a percent of n, so we calculate to find that 216 is 54% of 400. The point mn, for $n = 400$ and $m = 54$, is between curves A and B. The binomial odds are less than 19: 1, but the normal odds are considerably greater than 19: 1 that the men of race K really average shorter than the men of race J. The use of normal odds in this case is very probably justified because heights are known to be normally distributed and because the sample is large.

Fig. 3 shows that as the size of the sample increases there is a decrease in the percentage of the values which must fall on one side of any selected value in order to show a significant difference between the selected value and the true value of the mean which has been estimated. The decrease is very rapid for small samples. This shows why a small increase in the size of a small sample adds greatly to the confidence which can be placed in an average.

CONCLUSION

With the short method available, there is no virtue in using the longer, more tedious methods, and many averages can be tested for reliability which would not be tested by the longer methods.

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THE NODULATION AND OTHER ADAPTATIONS OF CERTAIN SUMMER LEGUMES[1]

J. F. DUGGAR[2]

THE chief object in conducting the field experiments here reported was to compare the less-known summer legumes with the kinds in common use with respect to nodulation, earliness, productiveness, palatability, and injury by common pests. The plants were grown at Auburn in 1928, 1929, and 1930 in rows 3 feet apart on upland Norfolk soil. Usually two or three plantings were made each season.

ROOT NODULE FORMATION AND RELATIVE EARLINESS OF SUMMER LEGUMES

It seemed especially desirable to learn which species would form nodules spontaneously on sandy acid soils, and which kinds, therefore, might here be independent of artificial inoculation, which was uniformly omitted. Periodic examinations were made of representative samples of the young seedlings to determine the percentage of plants supplied with one nodule or more. With some species the examinations were continued for several months and counts made on these to ascertain the average number of root nodules per plant.

Table 1 summarizes the data on nodulation and earliness, the latter as measured by number of days from emergence to the beginning of blooming.

On these sandy, acid soils there was complete or nearly entire failure to form any root nodules by *Dalea*, *Daubentonia* sp., *Sesbania*, wild sensitive vine (*Acuan*), young seedlings of black locust, wild perennial bean (*Dolicholus minimus*), navy bean, tepary bean, and bush lima bean. This indicates the need for artificially inoculating the seed of the three last-mentioned economic beans when grown for the first time. Yet adsuki, moth, "poultry," and rice beans, which belong with them in the same genus, *Phaseolus*, were able to develop root nodules in abundance without artificial inoculation.

This difference in nodulation between species within the same genus of beans is practically paralleled by two other cases elsewhere reported by the author. These showed (1) marked obstacles in Korean lespedeza plants (*L. stipulacea*) to cross inoculation with *L. striata*,[3] and (2) notable differences in the spontaneous nodulation of two types of peanut,[4] Runner and Spanish, both belonging to the same species, *Arachis hypogæa*.

The above facts as to *Phaseolus*, *Lespedeza*, and *Arachis*, together with nodulation studies of varieties of soybeans by other investigators, suggest that the usually accepted list of strains of bacteria

[1]Contribution from the Department of Special Investigations, Alabama Agriculture Experiment Station, Auburn, Ala. Received for publication November 9, 1934.

[2]Research Professor.

[3]DUGGAR, J. F. Differences between Korean and other annual lespedezas in root nodule formation. Jour. Amer. Soc. Agron., 26:917–919. 1934.

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capable of functioning in symbiosis with the legumes may need to be considerably extended.

With most species of summer legumes, delays in the date of planting and emergence hastened maturity, that is, shortened the interval between emergence and initiation of blooming.

On the basis of average figures following early, medium, and late planting, we may regard as *late* in blooming the common speckled velvet bean, "poultry" bean, mung bean, beggarweed, *Crotalaria*,

TABLE I.—*Days after emergence for at least 85% of seedlings to develop one nodule or more and for the beginning of blooming; plantings made in May, June, and July, 1928, 1929, and 1930.*

Plant	Usual no. days to early generalized nodulation	Relative no. nodules per plant	Average no. days to beginning of blooming
Prompt in Attaining Generalized Nodulation			
Cowpea, Brabham (*Vigna sinensis*)	5–7	Many	55
Soybean, Laredo (*Soja max*)	8–13	Many	48
Lespedeza, common* (*L. striata*)	8–14	Many	109
Lespedeza, Kobe* (*L. striata*)	8–14	Many	103
Lespedeza, Tenn. 76* (*L. striata*)	8–14	Many	107
Velvet bean, Early Speckled (*Stizolobium deeringianum*)	10–14	Medium	65
Velvet bean, Arlington	——	——	47
Velvet bean, Osceola	——	——	50
Velvet bean, Yokohama	——	——	54
Crotalaria striata	5–7	Many	62
Crotalaria sericea	5–7	——	73
Adsuki bean (*Phaseolus angularis or radiatus*)	7–13	Medium	45
Moth bean (*P. aconitifolius*)	9–10	——	——
"Poultry" bean (*P. calcaratus*), naturalized	4–13	Many	74
Rice bean (*P. calcaratus*)	7–13	Medium	42
Urd bean (*P. mungo*)	4–13	Medium	40
Wild annual bean, (*Strophostyles helvola*)	8–11	Many	44
Mimosa (*Albizzia julibrissin*)	13	Many	No bloom
Medium in Nodulating Time			
Beggarweed, Fla. (*Desmodium purpureum*)	19–24	Medium	62
Hyacinth bean (*Dolichos lablab*)	9–20	Medium	50
Mung bean, (*Phaseolus aureus*)	9–19	Few—medium	64
Runner peanut (*Arachis hypogæa*)	——	Many	28
Wild sensitive plant (*Chamaecrista nictitans*)	10–16	Many	——
Very Late in Nodulating			
Calopogonium mucuniodes	——	Few	——
Guar (*Cyamopsis tetragonoloba*)	31–48	Medium	50
Kudzu (*Pueraria thunbergiana*), first year from seed	37	Medium	No bloom
Lespedeza, Korean* (*L. stipulacea*)	30–70	Very few	71
Spanish peanut (*Arachis hypogæa*)	——	Few	23
Sword bean (*Canavalia ensiformis*)	19–40	Few	46

*Lespedezas planted early in April.

TABLE 1.—*Concluded.*

Plant	Usual no. days to early generalized nodulation	Relative no. nodules per plant	Average no. days to beginning of blooming
	Not Forming Nodules		
Bush lima bean (*Phaseolus luanatus*)...	——	None	38
Navy bean (*P. vulgaris*)............	——	None	44
Tepary bean (*P. acutifolius*).........	——	None	36
Wild perennial bean (*Dolicholus minimus*)........................	——	None	——
Black locust (*Robinia pseudacacia*)....	——	None	No bloom
Dalea (*D. alopecuroides*).............	——	None	51
Daubentonia sp..................	——	None	101
Sesbania macrocarpa...............	——	None	73
S. vesicaria......................	——	None	77
Acuan sp., first year from seed.......	——	None	No bloom

Sesbania, and the three native or naturalized perennial legumes, *Daubentonia*, sensitive vine (*Acuan*), and the small wild bean, (*Dolicholus minimus*).

Medium or intermediate in promptness of blooming were Yokohama, Osceola, and Arlington velvet beans, Brabham cowpea, Laredo soybean, hyacinth bean, guar, and sword bean. Early blooming plants included Spanish and Runner peanuts, rice bean, adsuki bean, urd bean, the three table beans, navy, tepary, and bush lima beans, and the wild annual legume from Ohio, *Strophostyles helvola*.

RELATIVE PRODUCTIVENESS

Observations and measurements of plants as grown in rows during each of three seasons justified the following general classification of the summer legumes tested on the basis of luxuriance of growth:

Large production of green material, usually coarse, velvet bean, kudzu, sword bean, *Crotalaria striata*, *C. sericea*, *Sesbania macrocarpa*, *S. vesicaria*, and *Daubentonia*.

Medium production of green material, usually of good quality, soybean (Laredo variety), cowpea (Brabham variety), "poultry" bean, rice bean, moth bean, hyacinth bean (rather coarse), mung bean (usually coarse), guar (rather coarse), beggar weed (sometimes coarse), wild sensitive plant, and Runner peanut.

Smaller production of green material, urd bean, adsuki bean, *Strophostyles helvola*, *Dolicholus minimus*, tepary bean (for seed), navy bean (for seed), bush lima bean (for seed), Spanish peanut, Kobe, Tennessee 76, Common, and Korean lespedezas, Acuan, and Dalea.

RELATIVE PALATABILITY OF CERTAIN SUMMER LEGUMES

Those species that showed most luxuriant growth were cut in October, 1928, in the rather late stages regarded as suitable for silage. The freshly cut forage was offered simultaneously to a herd of beef cattle of varied ages that was running on a good pasture. Table 2 shows the results of this test.

TABLE 2.—*Relative palatability for cattle of green forage of certain summer legumes.*

Plant	Stage of growth	Readiness with which eaten	Refused parts
Beggarweed	Early-pod stage, coarse stems	Ravenously and first	Only coarsest stems
"Poultry" bean	Filled green pods, good hay stage	Completely	None
Cowpea	⅔ pods colored	Readily	Only coarsest stems
Velvet bean	Late blooms and unfilled pods	Readily	Only largest stems
Hyacinth bean	Late-blooms and unfilled pods	Leaves only	All stems and most green pods
Mung bean	Most pods colored, leaves mildewed	Incompletely	Most stems and ripe pods
Crotalaria sericea	Late full bloom	Refused	All leaves and stems
Sword bean	Late bloom, flat, green pods	Refused	All leaves, pods, and stems
Guar	Late bloom, leafy	Refused	All leaves and stems

Beggarweed and "poultry" bean ranked first in palatability, followed in turn by the cowpea and velvet bean. The kinds that were entirely refused in the green condition were *Crotalaria* sp., sword bean, and guar.

Similar samples were harvested from the crop of 1930, run through a silage cutter, packed into burlap sacks, and imbedded in a silo while it was being filled with sorghum. This silo was opened after about 15 months and the cut silage of the legumes was separately offered to dairy cows and young heifers. The samples were offered in 33 pairs.

In six trials silage from soybean and velvet bean was eaten equally well and led all others in palatability. Next followed silage from mung bean and from guar. Even that from sword bean and *Crotalaria* sp. was eaten fairly well by most animals when preserved in close contact with sorghum silage.

RELATIVE INJURY BY MEXICAN BEAN BEETLE, NEMATODES, AND PLANT DISEASES

The summer legumes tested in these experiments differed widely in the extent to which their leaves were injured by the Mexican bean beetle, (*Epilachna corrupta*). Those that were most severely injured in seasons when this pest was rather abundant were navy bean, bush lima bean, and tepary bean. Florida beggar weed sometimes suffered material injury from this insect.

The plants that proved to be entirely or practically exempt from the attacks of the Mexican bean beetle were two species of *Crotalaria*, two species of *Sesbania*, guar, sword bean, *Dolicholus minimus*, *Chamaecrista nictitans*, *Acuan*, *Daubentonia*, black locust, mimosa, four annual *Lespedezas*, and Spanish and Runner peanut, and, in a single test, moth bean.

The kinds attacked but never materially injured by the Mexican bean beetle in these experiments included cowpea, soybean, velvet bean, kudzu, "poultry" bean, mung, rice, urd, and adsuki beans, hyacinth bean, and *Strophostyles helvola*.

The plants on which no root galls caused by the common nematode (*Heterodera radicicola*) could be found in any year were beggar weed, Laredo soybean, Brabham cowpea, peanut, *Crotalaria striata*, guar, *Dolicholus minimus*, and wild sensitive plant. Among the plants on which nematode galls were especially numerous were *Sesbania macrocarpa*, *S. vesicaria*, hyacinth bean, *Phaseolus calcaratus*, and other beans from India.

Especially susceptible to injury by leaf diseases, including a mildew, were mung, urd, and adsuki beans; less susceptible was the acclimatized variety of *Phaseolus calcaratus* which was obtained under the commercial name of "poultry" bean. The leaves of Brabham cowpea were sometimes attacked by mildew.

Guar was notably susceptible on acid soils to injury by a soil rootrot (*Sclerotium sp.*). This disease also attacked Korean Lespedeza.

PROMISING KINDS

Kobe and Tennessee 76 lespedezas were found decidedly more luxuriant in growth than the annual lespedeza that is commonly grown; otherwise these experiments afforded no evidence of decided superiority possessed by any little-grown summer legume over the cowpea, soybean, and velvet bean for the production of forage under usual conditions.

However, some of the less widely known summer legumes seemed to offer sufficient promise in one or more qualities to justify further experimentation as to their suitability for special conditions. This tentative list includes beggar weed, moth bean, the acclimatized variety of *Phaseolus calcaratus*, tepary bean, and possibly *Strophostyles helvola*.

The *Crotalarias*, *Sesbania macrocarpa*, and sword bean, all notable for their large production of coarse material, are of probable value under special conditions for soil improvement and possibly for other uses.

SUMMARY

Data are summarized for a number of summer legumes on promptness with which each became inoculated and on their relative earliness, luxuriance of growth, palatability, and extent of injury by Mexican bean beetle and nematodes.

Those found especially prompt in the spontaneous development of root nodules included Brabham cowpea, Laredo soybean, velvet bean, Common, Tennessee 76, and Kobe lespedezas, five species of *Phaseolus* from India, *P. calcaratus*, *Strophostyles helvola*, *Crotalaria striata*, and *C. sericea*.

Somewhat slower in nodulation but also naturally well supplied ultimately with root tubercles were Runner peanut, beggar weed, hyacinth bean (*Dolichos lablab*), mung bean, and wild sensitive plant (*Chamaecrista nictitans*).

There was complete or nearly complete failure to form nodules spontaneously by navy bean, tepary bean, bush lima bean, *Dolicholus minimus*, *Acuan*, *Daubentonia*, *Dalea*, *Sesbania macrocarpa*, and *S. vesicaria*. The apparent anomalies involved in the contrasting nodu-

lation behavior of various species of *Phaseolus*, of two species of annual lespedeza, and of the Spanish and Runner varieties of peanuts suggest the probable need for extending the usually accepted list of races of bacteria symbiotic with leguminous plants.

The list of legumes making most luxuriant growth included velvet bean, kudzu, *Crotalaria striata*, *C. sericea*, and *Sesbania macrocarpa*.

Silage from *Crotalaria sericea*, guar, and sword bean, all surrounded for months in the silo by sorghum silage, was eaten with fair relish by cattle, but the fresh forage from each of these three species was wholly rejected.

Uninjured by common pests were the following: (1) By the Mexican bean beetle, *Crotalaria*, *Sesbania*, guar, sword bean, *Dolicholus minimus*, *Chamaecrista nictitans*, annual lespedezas, and peanut; (2) by nematodes, beggar weed, Brabham cowpea, Laredo soybean, *Crotalaria striata*, guar, and *Dolicholus minimus*. Guar and Korean lespedeza were especially susceptible to a soil rootrot. Mung and urd beans were among the species most severely injured by leaf diseases.

Only Kobe and Tennessee 76 lespedezas proved to be superior on the whole to comparable legumes now in general use. However, sufficiently promising for further experimentation seemed *Crotalaria*, *Sesbania macrocarpa*, beggar weed, the late acclimatized form of *Phaseolus calcaratus*, moth bean, and possibly *Strophostyles helvola*.

INFLUENCE OF CORN SMUT AND HAIL DAMAGE ON THE YIELD OF CERTAIN FIRST-GENERATION HYBRIDS BETWEEN SYNTHETIC VARIETIES[1]

R. J. GARBER AND M. M. HOOVER[2]

IN an earlier paper (2)[3] some evidence was presented which indicated that yield in corn may not be reduced because of smut (*Ustilago zeæ*) to the extent that is commonly supposed. In this earlier work both with selfed lines and with first-generation crosses between them, the only significant decrease in yield was that attributable to the greater incidence of barrenness among smutted plants. On the other hand, somewhat similar studies conducted in Minnesota (3, 4) and in Ohio (5), with few exceptions, showed marked decreases in yield caused by smut. The more vigorous selfed lines and first-generation crosses as reported by Kyle (6) of the U. S. Dept. of Agriculture showed the greater number of smut boils. The purpose of this paper is to present additional data relative to the influence of smut on yield, and incidentally, to present some data which show the extent to which yields may be lowered because of hail damage.

MATERIAL AND METHODS

During the seasons of 1932 and 1933 certain first-generation hybrids between synthetic varieties were grown on the agronomy farm near Morgantown, W. Va. Each synthetic variety was made up from three to six selfed lines isolated from various varieties. The relative time of maturity and color of seed are indicated by the names of the synthetics as follows: Early Yellow, Medium Yellow, Medium White, Late Yellow, and Late White. The first generation crosses between Early Yellow and each of the others, as well as crosses between Medium White and Medium Yellow, were classified into Group I, and all other crosses into Group II on the basis of relative maturity.

Each first-generation hybrid was grown in single-row plats repeated six times in randomized blocks. The rows were approximately 136 feet long and 3½ feet apart, with the hills spaced 15 inches along the row. Two and three seeds were planted per hill and later the stand was thinned to a single stalk. The parental synthetic varieties and certain commercial varieties, namely, Lancaster Sure Crop, Reid's Yellow Dent, and Woodburn White Dent, were also included in the planting.

When the corn was about knee high an application of horse manure, which a few days previously had been treated with smut spores, was made. Two later similar applications were made at intervals of 10 days.

Detailed notes on smut infection as to size of boil and place of occurrence on each individual host plant were made twice during the growing season—late in August and about the middle of September. Additional notes on ear infection were made when the corn was harvested. The location of a smut boil was indicated by an appropriate descriptive note. For example, "neck" meant that the host carried

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[3]Reference by number is to "Literature Cited," p. 45.

a boil just below the tassel, and "above ear" that a boil appeared at the first or second node above the ear.

Yields both of grain and forage were determined after the ears or the entire plants were dried in a drying house to a moisture content of approximately 1%. Grain yields (shelled corn) were obtained from ears fully matured and forage yields from entire plants considered at the proper stage of maturity for ensiling. The yields of paired smutted and smut-free plants were in all cases from adjacent hills in the same row. The experiments in 1932 and 1933 were identical except that in the latter year grain yields were determined on some of the paired plants and forage yields on the remainder of the paired plants.

SMUT AND YIELDS

In Table 1 are shown the average differences between the yields of paired plants (smutted and smut-free) and their respective significance according to Fisher's (1) modification of Student's table. The four comparisons possible (column 5) with "tassel"-infected plants show three of them to be in favor of the smutted and one in favor of the smut-free plants, but none of the differences is significant. Four comparisons are also available involving "neck" infections and in this case one of the average differences between yields is significant, namely, the one obtained among the group 1 crosses grown in 1932. An average difference of 28.3 grams (P = .018) of shelled corn in favor of the smut-free plants was obtained. Similarly, among the paired "base"-infected and smut-free plants one significant average difference was found and here again it was with the earlier maturing or group 1 crosses. The average difference in this case is 31 grams in favor of the smut-free plants. The P value is .023 computed from 18 differences, a rather small number. Of the 12 average differences (column 5) listed in Table 1, 5 are in favor of the smutted plants and 7 in favor of the smut-free plants, although only two of these differences have any statistical significance (column 6).

TABLE 1.—*The average difference and its significance of yield in grams of grain per plant between smutted and smut-free corn plants in first generation crosses between synthetic varieties grown on the agronomy farm near Morgantown, W. Va.*

Group* of F_1 crosses	Year grown	Place of smut infection	Number of pairs	Average difference in yield, grams	Significance of difference P
(1)	(2)	(3)	(4)	(5)	(6)
I	1932	Tassel	38	6.1	0.5
II	1932	Tassel	10	− 2.2†	0.9
I	1932	Neck	39	28.3	0.018
II	1932	Neck	12	−13.0	0.6
I	1932	Base	100	10.1	0.1
II	1932	Base	63	8.1	0.4
I	1933	Tassel	63	− 4.6	0.6
II	1933	Tassel	17	−14.8	0.5
I	1933	Neck	101	19.7	0.4
II	1933	Neck	34	19.4	0.1
I	1933	Base	18	31.0	0.023
II	1933	Base	13	−10.6	0.5

*Group I earlier maturing; group II later maturing.
†Negative signs indicate difference is in favor of smutted plants.

In Table 2 are presented the average differences in yields of forage between paired plants grown in 1933. The differences are all small (column 4) and none of them is significant (column 5).

TABLE 2.—*The average difference and its significance between total dry weight of smutted and smut-free corn plants cut at the proper time for ensiling in first generation crosses between synthetic varieties grown on the agronomy farm near Morgantown, W. Va., in 1933.*

Group* of F_1 crosses	Place of smut infection	Number of pairs	Average difference in total weight, grams	Significance of difference P
(1)	(2)	(3)	(4)	(5)
I................	Tassel	82	1.4	0.9
II................	Tassel	34	1.6	0.9
I................	Neck	117	13.7	0.1
II................	Neck	47	—12.1	0.5
I................	Base	37	1.6	0.9
II................	Base	25	2.0	0.9

*Group I earlier maturing; group II later maturing.

If yield in corn is lowered by the presence of smut, one would naturally expect, as has been pointed out (4), that the size of the smut boil would be correlated with the extent of the decrease in yield. In this investigation smut boils of the approximate size of a hen's egg or larger were designated as size 4.

In Table 3 the average differences in yields between paired plants, one of which showed a size 4 smut boil and the other no smut, are shown. For the purpose of obtaining as large a number of comparisons as possible "below ear" and "base" (column 3) infections were considered together. No significant differences in yield (columns 5, 6, and 7) were found here. Among the plants grown in 1933 and infected

TABLE 3.—*The average difference and its significance between yield of smutted and smut-free corn plants where all smutted plants had at least a size 4 smut boil.**

Group of F_1 crosses†	Year grown	Place of smut infection	Number of paired plants	Ave. difference in yield, grams		Significance of difference P
				Grain	Forage	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
I..........	1932	Below ear and base	38	6.6		0.5
II..........	1932	Below ear and base	36	—1.0		0.9
I..........	1933	Below ear and base	20		20.2	0.3
II..........	1933	Below ear and base	12		—7.8	0.9
I..........	1933	Neck	48	25.5		0.018
II..........	1933	Neck	27	19.1		0.2
I..........	1933	Neck	72		25.8	0.017
II..........	1933	Neck	27		—4.1	0.8

*Smut boils as large as a hen's egg or larger.
†Group I earlier maturing; group II later maturing.

in the "neck" two significant average differences appeared. In the Group 1 crosses 48 smut-free plants yielded on the average 25.5 grams (column 5) more shelled corn than 48 similar plants with size 4 smut boils. An average difference of 25.8 grams in yield of forage (column 6) was obtained between 72 similar pairs of plants in the same crosses. These average differences are both significant and the fact that they are so nearly alike suggests that the reduction in yield of forage may be attributed primarily to the reduction in yield of grain. Of the eight comparisons shown in Table 3 only two gave average differences that were significant (column 7) and these significant differences, as in Tables 1 and 2, were obtained among group 1, the earlier maturing, first-generation crosses.

SMUT AND BARRENNESS

In this investigation, as in the one reported earlier (2), the presence of smut was associated with greater barrenness as shown in Table 4. The percentage of barren stalks in 1933 among the smut-free plants (column 4) in commercial varieties was 8.33; in synthetic varieties, 12.07; in F_1 crosses, group 1, 3.58; and in F_1 crosses, group 2, 5.71, whereas among the smutted plants the corresponding percentages were (column 7) 13.83, 13.0, 7.18, and 8.05 respectively. The differences in these percentages are appreciable (column 8) except the one for the synthetic varieties. In column 9 are shown the percentages of the total number of plants under observation that were smutted. The 1932 crop was considerably damaged by hail, but the data on relative barrenness among smutted and smut-free plants were similar to those obtained in 1933, although the incidence of smut was somewhat less during 1932. In this year the percentage of the total number of plants that showed smut boils among commercial varieties was 6.28; among synthetic varieties, 3.37; and among the F_1 crosses between synthetics, 3.94.

The location of the smut boils on barren plants is shown in Table 5. The total number of smutted barren plants studied in 1933 is shown in column 6 of Table 4. In 1932, the total number of barren smutted plants observed among the different sorts were as follows: Commercial varieties 16, synthetic varieties 30, and F_1 crosses between synthetics 107. It is apparent from Table 5 that in 1932 most of the barren plants were infected below the ear (columns 3 and 4), whereas in 1933 the greater infection occurred above the ear (columns 6 and 9). Ear infection (column 5), as one might expect, was an important cause of barrenness during both years. Inasmuch as the experiments in 1932 and 1933 were duplicates and conducted on the same plats of land, the difference in the results obtained must be due principally to season and probably to hail damage in particular. On July 7, 1932, a severe hail storm did considerable mechanical damage to the corn which at that time was about waist high. The abrasions caused by hail striking the lower part of the stalks which had developed at that time may have increased the incidence of smut in this region of the plant. Similar observations were made among the smutted plants that were not barren; i. e., smut boils occurred in a relatively high percentage of plants at "below ear" or "base" in 1932 and on the "neck" in 1933.

TABLE 4.—*The number of barren plants among smutted and smut-free corn plants grown on the agronomy farm near Morgantown, W. Va., in 1933.*

Name	Number of smut-free plants	Number of barren smut-free plants	Percentage of smut-free plants barren	Number of smutted plants	Number of barren smutted plants	Percentage of smutted plants barren	Difference between percentages	Percentage of plants smutted
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Commercial varieties	1,513	126	8.33	188	26	13.83	5.50	11.05
Synthetic varieties...	2,294	277	12.07	193	25	13.00	0.93	7.76
F_1 crosses, group I*..	4,862	174	3.58	529	38	7.18	3.60	9.81
F_1 crosses, group II*.	5,166	295	5.71	236	19	8.05	2.34	4.37

*Group I earlier maturing; group II later maturing.

TABLE 5.—*Location of smut boils on barren stalks.*

Name	Year grown	Percentage of total number of stalks showing smut infection at							
		Base	Below ear	Ear	Above ear	Leaf	Leaf sheath	Neck	Tassel
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Commercial varieties.....	1932	6.25	37.5	31.25	12.5	—	—	12.5	—
Synthetic varieties........	1932	3.33	56.67	26.67	10.0	—	—	—	3.33
F_1's between synthetic varieties.........	1932	14.02	36.45	25.23	11.21	1.87	—	7.48	3.74
Commercial varieties.....	1933	4.17	20.83	37.50	—	—	—	20.83	16.67
Synthetic varieties........	1933	—	5.26	21.05	5.26	5.26	5.26	36.84	21.05
F_1's between synthetic varieties........	1933	4.08	8.16	16.32	4.08	—	4.08	55.10	8.16

The results obtained in 1933 are probably more indicative of the reaction of the plants to smut that may be expected when grown under the conditions described during a season without hail.

HAIL DAMAGE AND YIELD

The hail storm of 1932 did considerable damage to the corn crop, but there were appreciable differences in extent of injury among individual plants. This presented an opportunity to make a study of the difference between yields (shelled corn) of paired plants, one of which was obviously damaged by hail and the other was not. All paired plants were adjacent in the same row and were free from smut boils. In Table 6 are shown the average yields (columns 3 and 4) and the differences between them (column 5) of 194 such paired plants among the group 1 F_1 crosses and 115 similar pairs among the group 2 F_1 crosses. The mean difference obtained in group 1 is 103.4 grams with a standard error of 8.3, and in group 2 125.4 grams with a standard error of 6. The differences in both cases are in favor of the plants not obviously damaged by hail. The reduction in average yield which may

TABLE 6.—*The average yields in grams of grain per plant of hail-damaged and not hail-damaged corn plants in first generation crosses between synthetic varieties grown on the agronomy farm near Morgantown, W. Va., in 1932.*

Group of F_1 crosses*	Number of pairs	Average yield in grams		Difference	Percentage reduction in yield due to hail
		Hail damaged	Not hail damaged		
(1)	(2)	(3)	(4)	(5)	(6)
I...........	194	76.0	179.4	103.4	57.6
II..........	115	76.7	202.1	125.4	62.0

*Group I earlier maturing; group II later maturing.

be attributed to hail damage was 57.6% in the group 1 crosses and 62.0% in the group 2 crosses (column 6). These estimates of reduction in yield are likely too low rather than too high because plants considered not obviously damaged may nevertheless have been damaged to some extent.

DISCUSSION AND SUMMARY

The data presented in this paper support those reported earlier from the West Virginia Experiment Station in showing that under the conditions described increased barrenness because of smut is the most important factor in reducing yield. In no case was a significant average difference in yield of forage or grain obtained between adjacent paired plants (smutted and smut-free) among the later maturing, first-generation crosses of synthetic varieties, even with those comparisons in which each one of the smutted plants carried at least one boil the size of a hen's egg or larger. On the other hand, among the earlier maturing F_1 crosses, of the six comparisons with yield of grain where size of smut boil was disregarded, two significant average differences in favor of the smut-free plant were obtained. When yield of forage was used as the criterion disregarding size of smut boil, no significant average differences were found. When comparisons were made only between paired plants, one of which carried at least one large smut boil, two (one for yield of grain and one for yield of forage) out of four average differences in favor of smut-free plants were found to be significant. These results suggest that smut injury may be more serious in early-maturing varieties such as would be grown in the northern part of the corn belt than among the later-maturing varieties.

In those cases where a significant reduction in average yield was obtained because of smut, the magnitude of the reduction was less than that obtained in the Minnesota investigation (3, 4). In Table 1, column 5, the 28.3 grams reduction in average yield is 17.2% of the average yield of the 39 smut-free plants in this comparison. Similarly, 31 grams in the same column represent 16.1% reduction in average yield. In Table 3, where comparisons were confined to heavily-smutted and smut-free plants, the two significant differences represent percentage reductions in yield of 15.4 (grain) and 10.4 (forage).

Contrary to what might be expected, smut boils located "above ear" and at "neck" caused more damage than those located "below ear" and "base." A similar observation was made by Immer and Christensen (3, 4). Of the four significant differences in average yield reported above, three were obtained between paired plants, one of which was smutted at the "neck," and the remaining difference was obtained between paired plants, one of which showed smut at the "base." The four comparisons of average yields of grain available for paired plants, one of which carried "tassel" smut (Table 1), show three differences in favor of the smutted plants, although these differences are not statistically significant.

Among the 57 barren smutted plants belonging to the first-generation crosses between synthetic varieties grown in 1933 (Table 5), 55.1% were smutted at the "neck." In 1932 smut located "below ear"

was predominantly associated with increased barrenness, but this may have been due to hail damage. During both years ear infection, as one might expect, accounted for considerable increased barrennes attributable to smut.

In contrast to the relatively small damage caused by smut in corn grown in 1932 and 1933 under the conditions described, a marked decrease in yield during the former year was caused by a hail storm that occurred on July 7. The decrease in average yield between paired plants attributable to hail injury was 57.6% among the earlier-maturing, first-generation crosses and 62% among the later-maturing ones.

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THE AVAILABLE PHOSPHORUS AND POTASSIUM CONTENTS OF SURFACE SOILS AND SUBSOILS AS SHOWN BY THE NEUBAUER METHOD AND BY CHEMICAL TESTS[1]

S. F. THORNTON[2]

BOTH practical observations and scientific investigations have shown that subsoils usually are much less productive than surface soils. This is especially true for non-legume crops. However, the nature of the cause of the failure of plants to make satisfactory growth on subsoil material is still a disputed question. It has been attributed to lack of available nutrients, soil reaction, presence of toxic substances, lack of proper aeration, and undesirable physical conditions. Work on this problem during recent years has been confined largely to pot tests and field observations. Because of the large amount of work involved in such tests only a relatively few soils have been investigated.

EARLIER WORK

Alway, McDole, and Rost (1)[3] found that the subsoil material of Nebraska loess soils was unproductive with corn but showed no rawness towards inoculated legumes. They made the further observation that unproductivity of subsoils from humid regions towards inoculated legumes is probably due to lack of availability of phosphoric acid or potash, or both.

Lipman (8) immediately questioned the existence of humid subsoils which were sterile towards inoculated legumes and denied that lack of phosphoric acid or potash could be the cause of such unproductivity.

Harmer (3) found some of the humid Minnesota subsoils to be as productive with inoculated alfalfa as the corresponding surface soils. Others, however, he found quite unproductive. Such unproductivity was associated with neither an especially low nitrogen content nor a lack of carbonates.

McMiller (7) used alfalfa in pot tests to show that certain Minnesota subsoils which previously had been found "raw" towards inoculated legumes were rendered as productive as the corresponding surface soils when soluble phosphorus and potassium fertilizers were added.

Millar (4, 5, 6), from work with several soil types, concluded that the poor growth of corn in soil from A_2 and B horizons is due very largely to a lack of available nutrients and that very large quantities, particularily of phosphorus, must be added to satisfy the adsorptive capacity of the soil and make plant growth commensurate with that obtained when surface soil is used.

Conner (2) carried out pot tests with wheat on surface soil and subsoil horizons of Crosby and Clyde silt loam soils. Nitrogen and phosphorus were found to be very deficient in all subsoils as compared to surface soils. Potash and lime were less deficient than either nitrogen or phosphorus.

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[1]Contribution from the Department of Agricultural Chemistry, Purdue University Agricultural Experiment Station, Lafayette, Ind. From a part of a thesis submitted to the faculty of the Graduate School of Purdue University in partial fulfillment of the requirements for the degree of doctor of philosophy. Also presented at the annual meeting of the Society held in Washington, D. C., Nov. 22 and 23, 1934. Received for publication November 28, 1934.

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[3]Figures in parenthesis refer to "Literature Cited," p. 50.

THE PRESENT INVESTIGATION

In so far as the writer is aware no data are available to show the relative available phosphorus and potassium contents of a large number of surface soils and subsoils. Such data are necessary before general conclusions can be drawn regarding the relative mineral nutrient contents. It is hoped that the present work will serve as a contribution towards this end.

The chief difficulty in securing such data is in finding a method which is sufficiently simple and rapid to make possible a large number of determinations and that at the same time gives reliable indications of actual availability to plants. The Neubauer method has been found best to fulfill these requirements. Details of the procedure used have been given in an earlier work by the author (9). For comparative purposes, data are also given for chemical tests for both phosphorus and potassium. The procedures used are the rapid chemical tests recently described by Thornton, Conner, and Fraser (10). These tests indicate the relative amounts of dilute acid-soluble phosphorus and water-soluble and replaceable potassium.

The samples tested represent arbitrary depths rather than definite horizons, surface soils representing the top 6 to 8 inches and subsoils the second 6 to 8 inches. Thus, the surface soils represent approximately the cultivated area. All results are expressed in pounds per acre on the basis of 2,000,000 pounds.

Table 1 gives the average pH and the average Neubauer values for 460 soils listed according to the states from which they were obtained. With the exception of Indiana it is felt that the number of soils from each state is too small to be taken as definitely representative of average conditions. However, some important trends are indicated.

TABLE 1.—*Neubauer tests for 460 soils from various locations.*

Location	No. of samples	pH		Lbs. P_2O_5 per acre		Lbs. K_2O per acre	
		Surface soil	Subsoil	Surface soil	Subsoil	Surface soil	Subsoil
Indiana....	219	5.9	5.9	59	37	219	182
Ohio.......	31	5.9	5.9	49	27	212	214
Iowa.......	31	6.8	6.8	87	48	412	261
Kentucky...	16	6.1	6.0	78	60	339	315
Maryland...	74	6.1	6.0	72	57	337	249
California...	57	7.0	7.0	189	143	678	627
Misc.......	33	6.2	6.2	72	62	250	244
Average..	460	6.2	6.2	80	56	314	265

The average pH of the surface soils and the subsoils is practically identical in all cases and, for the majority of soils, is approximately 6.0. Definitely higher values are indicated for Iowa and California.

In comparison with the corresponding surface soils, the available phosphorus content of the subsoils is low in every instance. This is especially true for Indiana, Iowa, and Ohio. In contrast, the Cali-

fornia soils show much higher values for surface soils and also relatively high subsoil values.

The available potash content of the subsoil usually is found to be somewhat lower than that of the surface soil. However, this relation is neither as consistent nor as pronounced as for phosphorus. The California soils show unusually high values for both surface soils and subsoils.

Results of the chemical tests are given in Table 2. Because the upper range of the chemical tests is not as high as the values sometimes obtained with the Neubauer method, values in Table 2 are usually somewhat lower than those given in Table 1. This is especially true for potassium.

TABLE 2.—*Chemical tests.**

Location	No. of samples†	pH		Lbs. P_2O_5 per acre		Lbs. K_2O per acre	
		Surface soil	Subsoil	Surface soil	Subsoil	Surface soil	Subsoil
Indiana..	170	5.9	5.9	61	57	165	170
Ohio......	21	5.9	5.9	48	63	174	196
Iowa......	31	6.8	6.8	118	93	176	101
Kentucky..	15	6.1	6.0	46	40	252	222
Maryland..	74	6.1	6.0	70	34	246	161
California..	57	7.0	7.0	150	139	329	271
Misc......	32	6.2	6.2	104	101	178	162
Average.	400	6.2	6.2	82	70	209	180

*Described in Purdue Univ. Agr. Exp. Sta. Circ. 204. 1934.

†Samples of 60 of the soils reported in Table 1 had been exhausted and thus were not available for chemical tests.

For phosphorus the chemical tests do not give such relatively low values for subsoils, in most cases the values for surface soils and subsoils being quite close together. From these data it appears that the dilute acid-soluble phosphorus content of surface soil and subsoil is usually quite similar. In previous work it has been found that on surface soils such tests serve as reliable indicators of phosphorus availability, but on subsoils they tend to give values that are too high.

As was true for the Neubauer method, chemical tests indicate a slightly lower available potassium content for subsoils as compared to the corresponding surface soils.

Since a few very high results may raise markedly the average for a large number of samples, the average analysis does not always best express the true conditions. The relative number of samples which are deficient has been found to be a valuable supplement to the data already discussed. Table 3 contains such data. They serve to emphasize the points already advanced. Especial mention may be made of the high percentage of subsoils which are deficient in available phosphorus.

In Tables 4, 5, and 6 the Indiana soils have been grouped according to pH. No especially significant correlation between pH and available phosphorus or available potassium as shown by the Neubauer method

is to be observed. However, for both phosphorus and potassium and with both surface soils and subsoils slightly higher values are given in the 6.1 to 6.5 group. The greatest number of soils are to be found in the 5.6 to 6.0 group.

TABLE 3.—*Percentage of soils deficient in phosphorus and potash.*

Location	Surface soil				Subsoil			
	Phosphorus		Potash		Phosphorus		Potash	
	Neubauer	Chemical	Neubauer	Chemical	Neubauer	Chemical	Neubauer	Chemical
Indiana....	78	73	65	74	96	75	65	72
Ohio......	90	81	60	81	94	70	55	71
Iowa......	61	35	42	74	97	52	55	84
Kentucky..	70	80	19	47	75	87	19	67
Maryland..	70	70	45	50	81	93	51	73
California..	19	9	0	21	33	16	0	37
Misc.......	64	41	50	66	70	44	55	84
Average..	68	37	49	61	83	66	51	69

TABLE 4.—*Neubauer tests at different pH levels (Indiana soils).*

pH	Surface soil			Subsoil		
	No. of samples	Lbs. per acre P_2O_5	Lbs. per acre K_2O	No. of samples	Lbs. per acre P_2O_5	Lbs. per acre K_2O
——5.0	14	56	208	27	34	131
5.1–5.5	42	51	235	45	29	146
5.6–6.0	69	60	210	53	38	193
6.1–6.5	53	67	250	38	46	221
6.6–7.0	27	52	188	36	40	199
7.1——	11	65	143	15	36	190

TABLE 5.—*Chemical tests at different pH levels (Indiana soils).*

pH	Surface soil			Subsoil		
	No. of samples	Lbs. per acre P_2O_5	Lbs. per acre K_2O	No. of samples	Lbs. per acre P_2O_5	Lbs. per acre K_2O
——5.0	12	34	203	20	21	216
5.1–5.5	35	37	172	43	21	143
5.6–6.0	58	55	161	44	46	165
6.1–6.5	38	78	175	32	97	201
6.6–7.0	17	81	125	22	107	157
7.1——	7	124	132	7	120	123

Data for the chemical tests (Table 5) do show an interesting correlation with pH. For both surface soils and subsoils the available phosphorus content shows a gradual increase with increasing pH and a

TABLE 6.—*Percentage of soils (Indiana) deficient in phosphorus and potash.*

pH	Surface soils				Subsoils			
	Phosphorus		Potash		Phosphorus		Potash	
	Neubauer	Chemical	Neubauer	Chemical	Neubauer	Chemical	Neubauer	Chemical
—5.0	80	92	50	67	96	95	66	50
5.1–5.5	88	86	67	71	100	100	78	90
5.6–6.0	83	83	70	76	94	86	62	70
6.1–6.5	65	63	60	76	97	44	89	60
6.6–7.0	80	47	70	76	92	41	50	91
7.1—	64	14	82	86	100	57	87	71

marked increase when the neutral point is passed. The increase is more rapid with subsoils than with surface soils. It appears that such chemical tests may be expected to give somewhat low results for the very acid soils, somewhat high results for the neutral and slightly acid soils, and much too high results with alkaline soils. The results of such tests on alkaline soils have proved unreliable.

For potash there is a tendency for the chemical tests to give somewhat lower values with increasing pH.

From a comparison of the Neubauer and chemical test data it appears that for phosphorus solubility in dilute acids increases with increasing pH more rapidly than does availability to plants, while for water-soluble and replaceable potassium the reverse is true.

SUMMARY AND CONCLUSIONS

Comparative data for surface soils and subsoils are given for 460 soils with the Neubauer method and 400 soils with chemical tests.

With the Neubauer method, subsoils as compared to surface soils show a much lower available phosphorus content. For soils from the Middle West, subsoils are phosphorus deficient in almost all cases.

Neubauer values for available potassium are only slightly lower with subsoils than with corresponding surface soils.

With chemical tests subsoils appear to be relatively only slightly lower in available phosphorus and slightly lower in available potash.

With the Neubauer method there appears to be little correlation between pH and available phosphorus and potassium content.

With chemical tests the phosphorus values increase with increasing pH and the potassium values show somewhat the reverse tendency.

The data presented indicate that for subsoils of the humid regions at least, phosphorus deficiency is an important factor in the unproductivity so often observed.

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NITROGEN, PHOSPHORUS, AND POTASSIUM REQUIREMENTS OF INDIANA SURFACE SOILS AND SUBSOILS[1]

S. D. CONNER[2]

OVER three-fourths of the agricultural lands of the country are more or less subject to erosion. The surface soils of today were the subsoils of yesterday, and it is safe to say that the subsoils of today will be the surface soils of tomorrow. Therefore, it is vitally important that we find the fertility possibilities of our subsoils. While natural forces gradually change the barren eroded soils into a much more productive condition, this is only a gradual change. If we know the deficiencies of subsoils, we are in a position to speed up this process. Chemical methods are of some value in determining the availability of soil constituents, but tests by means of growing crops are much more to be depended upon than is the solvent action of chemicals.

The work reported in this paper is a continuation of the investigations presented at the tenth annual meeting of the American Soil Survey Association held in Chicago in 1929 and published in Bulletin XI of that Association.

Complete fertility pot tests have been conducted with five Indiana surface and subsoils, the description and analysis of which are shown in Table 1. These soils vary from poorly drained to well drained and from thin high land to rich alluvial bottom land.

Ammonium nitrate, mono-calcium phosphate, potassium chloride, and calcium carbonate were mixed with the soils at the start, in various combinations, including complete treatment and in other combinations with one ingredient omitted. Nitrogen was added to the nitrogen pots for the second wheat crop. Minerals were applied only on the first crop.

Four crops were grown in succession on soils from four horizons of Crosby silt loam, a naturally level poorly drained type of upland soil. This soil was taken from the soils and crops experiment farm at Lafayette, Ind. It is now tile drained with the tiles about 3 feet deep and 59 feet apart. This soil has a rather heavy B horizon and the tile should be much closer to furnish adequate drainage. Fig. 1 shows the tile effect on corn on this land. Lack of drainage between tile lines prevents deep rooting of corn and other crops. On areas where little or no potash is applied, potash starvation causes depressed yields. This depressed growth of corn showing potash starvation symptoms is not seen where manure or fertilizer supplying adequate potash has been used. Root studies show that corn does not root much deeper than plow depth half-way between tile lines, but near the tiles it roots 3 or 4 feet deep, thus being able to secure potash as well as moisture from the subsoil.

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[1]Contribution from the Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Indiana. Also presented at the annual meeting of the Society held in Washington, D. C., November 22 and 23, 1934. Received for publication November 28, 1934.

[2]Research Chemist.

TABLE 1.—*Description of soils used in pot tests.*

Soil type	Depth in inches	Drainage	Neubauer tests		Chemical tests*			
			P	K	N,%	P	K	pH
Bethel silt loam...	0–6	Very poor			0.13	Very low	Very low	6.0
Bethel silt loam ..	6–15	Very poor			0.09	Very low	Low	5.0
Crosby silt loam...	0–6	Poor	3.7	4.3	0.09	Low	High	5.5
Crosby silt loam..	6–15	Poor	2.9	6.5	0.04	Very low	Very high	5.7
Crosby silt loam.	15–30	Poor	2.9	9.1	0.04	Medium	Very high	6.3
Crosby silt loam ..	36–48	Poor	4.8	9.1	0.03	High	Medium	8.0
Clyde silty clay loam.........	0–6	Good	5.1	9.1	0.20	High	High	6.2
Clyde silty clay loam..........	6–15	Good	2.2	9.7	0.08	Very low	Medium	6.4
Clyde silty clay loam..........	15–30	Good	1.5	9.7	0.04	Medium	Low	6.8
Warsaw loam....	0–6	Very good	2.3	9.7	0.17	Very low	Low	5.6
Warsaw loam. ...	6–15	Very good	2.2	10.9	0.10	Very low	Low	5.6
Genesee silt loam..	0–6	Good	7.7	31.5	0.29	High	Very high	8.0
Genesee silt loam..	6–15	Good	6.7	32.7	0.32	Low	Medium	8.0

*Phosphorus and potassium determined with rapid method, giving dilute acid soluble phosphorus and exchangeable potassium. See Purdue Univ. Agr. Exp. Sta. Circ. 204.

FIG. 1.—Corn on Crosby silt loam is much better near tile than it is between tile lines.

Fig. 2 shows the relative yields of the various crops on all horizons. The most striking point illustrated is the rapid decrease in yields of all crops the deeper the soil layer when phosphorus is omitted. This is also shown where nitrogen is omitted on wheat, but not with legumes. Where phosphate and nitrogen are added the subsoil horizons yield almost as much as the surface soil. When potash is omitted it is seen that in most cases the subsoils are able to furnish adequate supplies of potash. The PKCa treatment without nitrogen gave very small yields,

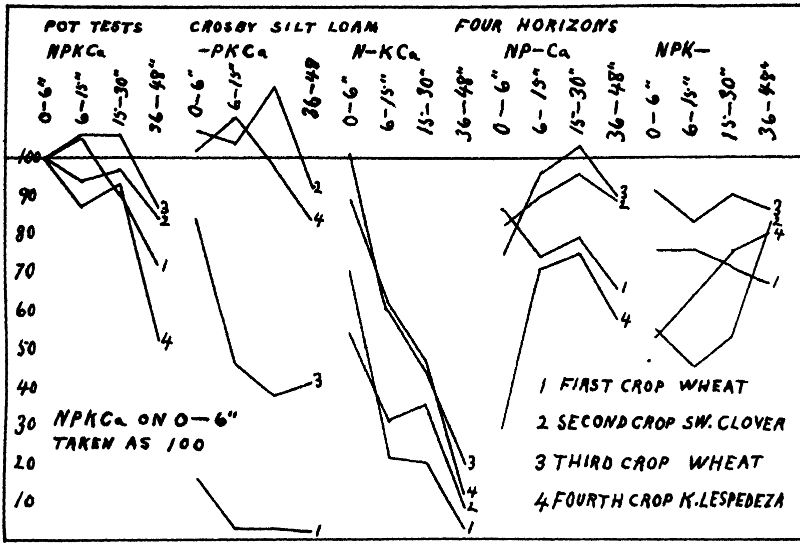

FIG. 2.—Relative yields of pot tests on four horizons of Crosby silt loam with four successive crops and various fertilizers.

with wheat, the first crop, even on the surface soil. This soil was taken from the field in October when nitrates were at a very low level. Other investigations as well as this show a very low nitrogen efficiency in

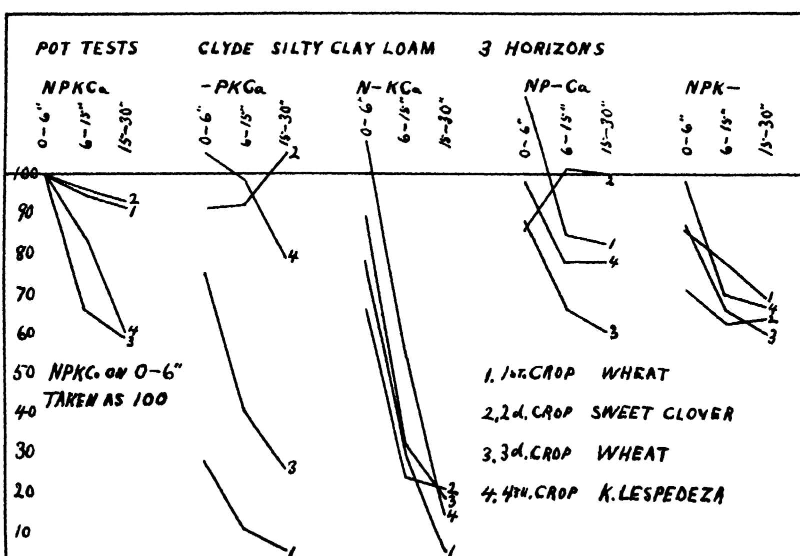

FIG. 3.—Relative yields of pot tests on three horizons of Clyde silty clay loam, with four successive crops and various fertilizers.

pot tests even on nitrogen-rich soils when soil is taken from the field in late fall or winter. In Fig. 2 it will be seen that the second wheat crop with PKCa is relatively at a very much higher level, particularly on the surface soil. While this may be partly explained as a legume effect, other tests where no legume was used show similar results.

Fig. 3 shows the results of pot tests on three horizons of Clyde silty clay loam, a naturally poorly drained high land depression soil, very rich in organic matter and of naturally high fertility. This soil is also

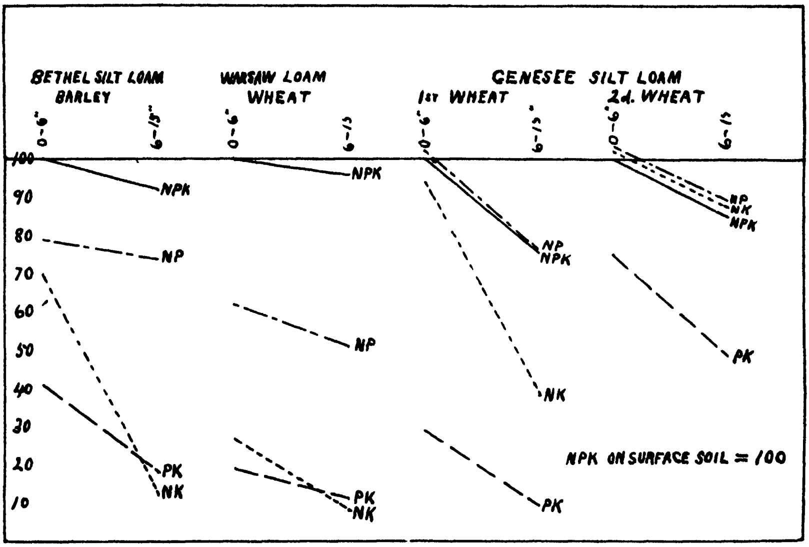

FIG. 4.—Relative yields of pot tests on three soils and two horizons, with various fertilizers.

from the soils and crops farm and is tiled and apparently now adequately drained, as it does not show the tile effect seen on the adjoining Crosby. These results show a very similar picture to that in Fig. 2; low nitrogen and phosphorus in the subsoils and good supplies of potash in the lower horizons. Neither of these soils nor their subsoils are acid enough to show any serious lime deficiency. What lime response there is seems to be relatively as great in the surface as in the subsoil horizons.

Fig. 4 gives results of pot tests on surface and subsoil horizons of three soils, using NPK, PK, NK, and NP treatments. The Bethel silt loam from Miami County is a flat, very poorly drained upland soil. The Warsaw loam is a level very well drained dark soil of prairie origin from Tippecanoe County. The Genesee silt loam is a well drained soil from the Wabash River bottoms. This soil is of rather recent origin. The subsoil is higher in organic matter and nitrogen than the surface soil.

The level and slope of the graphs for each fertilizer treatment indicate that, in general, nitrogen and phosphorus are relatively more

deficient in the subsoils than in the surface soils. With the PK treatment on the Genesee soil, the second wheat crop is relatively much better than the first wheat crop in both the surface and subsoil. In this comparison there is no legume crop to add nitrogen. The greater efficiency of the soil nitrogen in the second crop over the first is due to other effects, probably aeration and nitrification. A similar change in efficiency of soil phosphorus may be observed in the NK yields, the second wheat crop showing no response for phosphate in the subsoil, while there was a distinct lack of phosphate in the first wheat crop.

The tendency for the phosphorus and sometimes the nitrogen of soils and subsoils to increase gradually in efficiency as they are exposed to drying aeration and heat in the greenhouse in the summertime between crops has often been noted in pot experiments when the same soil has been cropped for more than one year. This increase in availability is one method nature may have in causing old eroded soils gradually to accumulate available nitrogen and phosphorus.

SUMMARY

In general, when Indiana subsoils are tested in pot cultures, they show a greater need than do the surface soils for phosphorus for both legumes and nonlegumes. This need is often greater the further from the surface the soil is taken.

Nitrogen is more deficient for grain crops in subsoils than it is in surface soils. Subsoils did not show a deficiency of nitrogen when inoculated legumes were grown.

When more than one crop was grown on the same subsoil, the first crop was relatively more in need of nitrogen and phosphorus than were the succeeding crops.

Eroded surfaces and subsoils exposed in regrading operations or in fills using subsoil, are in need of liberal phosphate and nitrogen fertilization when seeded down to nonlegumes. Legumes on such surfaces should be inoculated and heavily fertilized with phosphates. Lime is of course needed where the soil is acid.

Potash may in some cases be needed on eroded surfaces, but in general, Indiana subsoils are in no greater need of potash than are surface soils.

PASTURING ALFALFA IN MICHIGAN[1]

H. C. Rather and A. B. Dorrance[2]

THIS discussion of some phases of alfalfa pasture under Michigan conditions is based primarily on experiments conducted at the W. K. Kellogg Farm of the Michigan State College located at Augusta, in southwestern Michigan. To check on some of the general principles which these trials have indicated, questions regarding them were taken up in some detail with 35 Michigan farmers regularly using alfalfa for pasture. The idea is not advanced that the opinions of these men accurately indicate the collective judgment of all Michigan farmers who have opened their alfalfa meadows to their livestock. Rather, a few of their ideas, summarized, are presented as an interesting and significant expression by men with an average of more than 10 years' experience in the use of alfalfa for pasture under conditions demanding the economic soundness of the enterprise.

ALFALFA VS. SWEET CLOVER FOR PASTURE

By ratio of 30 to 2 these farmers expressed their preference for alfalfa over sweet clover as a pasture crop.

"It is just as easy to get a stand with alfalfa as with sweet clover," they say, "alfalfa lasts more years, provides a longer grazing season, better and more palatable forage." The fact that second-year sweet clover is through as a pasture crop by about July 15 in Michigan, although the grazing season is only half over, is an important disadvantage. Pasture returns may normally be expected from sweet clover only in its second year, for much of Michigan's soil is of the lighter types on which this crop does not make enough growth during the year it is seeded to provide any fall pasture.

Typical of many areas in southwestern Michigan is the Bellefontaine sandy loam soil at Augusta on which a comparison of alfalfa and sweet clover pasture gave results in support of the preference of these farmers for alfalfa.

The seedings of alfalfa and sweet clover were made in duplicate 1-acre paddocks in 1930, following a 1929 application of 7 yards per acre of marl and treatment with commercial fertilizer. In 1931 the alfalfa furnished 613 sheep-days pasture per acre, the sweet clover 343. Both stands were good but even during June and July the alfalfa furnished the greater amount of pasture, while in August and September the sweet clover yielded nothing at all. Two years later the same sweet clover paddocks again were ready for grazing, this time in comparison with the old alfalfa already closely cropped by sheep for two seasons.

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[1]Contribution from the Section of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich., and the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. Journal Article No. 192 (new series) of the Michigan Agricultural Experiment Station. Also presented at the annual meeting of the Society held in Washington, D. C., November 22 to 23, 1934. Received for publication December 3, 1934.

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The alfalfa yielded 821 sheep-days of pasture per acre, while 590 sheep-days were secured from the sweet clover.

ALFALFA AND PERMANENT GRASS PASTURES COMPARED

Permanent grass pastures in Michigan consist primarily of Kentucky bluegrass with a natural mixture of white clover, under favorable conditions. On the poorer soils Canada bluegrass is likely to predominate. The old meadows at Augusta are typical of those in southwestern Michigan, rolling in contour and running to Canada bluegrass and sorrel. Fertilization and reseeding has made possible the reestablishment of Kentucky bluegrass but, during the past 5 years, mostly dry years, white clover has failed to make a showing. On such an area, another field of Bellefontaine sandy loam soil, alfalfa pasture was compared with old grass pastures and newly seeded ones, the grasses being grown with and without fertilizer and lime treatments. The grazing results are given in detail for 1932 in Table 1, carrying capacity for 3 years in Table 2, and the fertilizer, lime, and seeding treatments in Table 3.

TABLE 1.—*Comparison of pasture returns from alfalfa and permanent grass pasture, W. K. Kellogg farm, Augusta, Mich., 1932.**

Crop	Lamb-days per acre	Gain, lbs. per acre	Total lbs. of grain fed per acre	Value of barley consumed per acre of pasture at 30 cents per bushel	Total value of gains at 5.5 cents per pound	Acre returns from pasture less cost of grain	1932 fertilizer charges†	Returns after deducting grain costs and 1932 fertilizer charges
Alfalfa	1,873.5	392.3	1,028	$6.42	$21.58	$15.16	$4.83	$10.33
Pasture mixture, two nitrogen applications	1,367.0	259.3	643	4.02	14.26	10.24	9.07	1.17
Fertilized sod	698.0	179.0	370	2.31	9.85	7.54	8.02	—0.48
Pasture mixture, one nitrogen application	1,120.5	122.6	413	2.58	6.74	4.16	8.02	—3.86
Unfertilized sod	456.5	99.5	298	1.87	5.47	3.60	None	3.60
Unfertilized pasture mixture	459.5	85.9	280	1.75	4.72	2.97	None	2.97

*From Dorrance, A. B., Brown, G. A., and Rather, H. C. Experiments with permanent pasture for sheep. Mich. Exp. Sta. Quart. Bul., 15, No. 2. 1933.

†Fertilizer charges made against 1932 returns are all costs of nitrogen applied in 1932, 60% of the 0–14–14 applied in 1932, and ⅓ of the 2–16–6 applied in 1930. All other fertilizers previously applied are chargeable to previous seasons.

TABLE 2.—*Comparative carrying capacity of alfalfa and permanent grass pasture at the W. K. Kellogg Farm, Augusta, Mich., 1931, 1932, and 1933.*

Crop	Carrying capacity in terms of sheep-days per acre*			
	1931	1932	1933	Average
Alfalfa	613	937	821	790
Pasture mixture, two nitrogen applications	552	684	558	598
Fertilized sod	608	349	279	412
Pasture mixture, one nitrogen application	379	560	308	416
Unfertilized sod	222	228	251	234
Unfertilized pasture mixture	207	230	329	255

*Where lambs were used, two lambs were considered the equivalent of one ewe in determining a "sheep-day".

At the beginning of the 1933 grazing season timothy had passed out of all the paddocks where it was sown in 1930. At this time there was a pure sod of Kentucky bluegrass on those paddocks receiving nitrogen twice a year, a mixture of red top and Kentucky blue grass with a small amount of Canada bluegrass on those receiving nitrogen only in the spring, and almost pure red top on the unfertilized areas originally seeded to the pasture mixture. The old sods consisted mostly of Canada bluegrass and, in unfertilized paddocks, weeds.

This was not primarily a fertilizer experiment but rather a comparison of different pasture crops. That alfalfa on limed and fertilized soil should outyield native grass pastures without such treatment was to be expected. However, the fertilization of these old pastures or the establishing of new grass pastures on this land by reseeding and fertilization has thus far failed to yield returns in relation to costs comparable to those from alfalfa pasture. Furthermore, the major part of the increase in yield of the fertilized grass pastures has come in the moist months of the spring. With the advent of the dry hot weather of July and August the fertilized grasses have quit growth just as completely as the unfertilized and have yielded only small amounts of summer pasturage in some seasons, none at all in others. Alfalfa has been more productive of pasturage than these grasses both in the spring and in the summer.

The results for the 1932 season are presented in greater detail because a uniform group of western lambs was used in pasturing off the various paddocks and comparative gains of these lambs add to the significance of the results. Also, the summer of 1932 was fairly favorable to grass pastures from a moisture standpoint, there being 4.11 inches of rainfall in July and 2.83 inches in August, the latter nearly normal and the former 0.95 inch above normal. In every other year of these comparisons rainfall for July and August was substantially below

TABLE 3.—*Record of seedings and treatments of paddocks listed in Tables 1 and 2.**

Crop		Seeding		Fertilizer treatments				
No.	Kind	Kind	Rate in lbs. per acre	1929	1930	1931	1932	1933
1	Alfalfa	Grimm	10	300 lbs. per acre 2–16–6	300 lbs. per acre 2–16–6	None	300 lbs. per acre 0–14–14	None
2	Pasture mixture, two nitrogen applications	Kentucky bluegrass Canada bluegrass Red top Timothy Alsike Red clover White clover	6 3 3 4 2 2 2	300 lbs. per acre 2–16–6	300 lbs. per acre 2–16–6 100 lbs. of nitrate of soda in early July	100 lbs. sulfate of ammonia in spring; 100 lbs. nitrate of soda in early July	300 lbs. per acre 0–14–14; 100 lbs. sulfate of ammonia in spring; 100 lbs. nitrate of soda in early July	100 lbs. sulfate of ammonia in early spring; 100 lbs. nitrate of soda in early July
3	Fertilized sod	None	—	300 lbs. per acre 2–16–6	300 lbs. per acre 2–16–6	100 lbs. sulfate of ammonia in spring	300 lbs. per 0–14–14; 100 lbs. sulfate of ammonia in spring	100 lbs. sulfate of ammonia in spring
4	Pasture mixture, one nitrogen application	Same as No. 2	Same as No. 2	Same as No. 3	Same as No. 3	Same as No. 3	Same as No. 3	Same as No. 3
5	Unfertilized sod	None		None	None	None	None	None
6	Unfertilized pasture mixture	Same as No. 2	Same as No. 2	None	None	None	None	None

*All paddocks for numbers 1, 2, 3, and 4 were limed with 7 yards of marl per acre in 1929. Numbers 5 and 6 were unlimed and were strongly acid. All seedings failed in 1929 because of drought, and repetition of original fertilizer and seeding treatments was made in 1930. Seedings in 1930 were successful.

normal and the advantages of the alfalfa during these dry periods were even more marked than in 1932.

It may be added that the experience of those Michigan farmers questioned on alfalfa pasture is in accord with the results of this comparison, for 27 out of 28 stated that their grazing returns from alfalfa were far superior to those from permanent grass pasture.

MANAGEMENT OF ALFALFA FOR PASTURE

So many problems are involved in the management of alfalfa pasture that a single experiment must be limited in its application. Grimm alfalfa seeded on a Fox sandy loam soil at Augusta in 1929 was used to obtain information on the carrying capacity and suitability of alfalfa pasture for dairy cows and the influence of pasturage on the alfalfa as compared with cutting the crop for hay. The stand was established with a nurse crop of Spartan barley after the soil had been limed with 7 yards of marl per acre and fertilized with 300 pounds per acre of 2–16–6. The 1930 crop was cut for hay and grazing comparisons were started in 1931 in accordance with plans described in Table 4.

CONTINUOUS GRAZING

Michigan farmers, who have little or no grass land for permanent pasture, depend on shorter-lived crops throughout the grazing season. Rye, sweet clover, Sudan grass, and alfalfa are commonly used, and on such a farm it is desirable to use alfalfa for pasture in the spring as well as in the summer. Sometimes pasturage on alfalfa is started as early as May 1, though more frequently farmers report that they wait until May 15 to 25.

The number of animals on the pasture should be large enough to prevent the plants from maturing too quickly. In the 1930 trials at Augusta the start of grazing was delayed and the number of animals held down and as a result the alfalfa matured, became unpalatable, and produced only 66 cow-days of pasture for the season. In 1932 and 1933 grazing was started earlier and the number of cows adjusted so as to keep about an 8- to 12-inch growth of alfalfa. E. W. Ruehs, a Kent County dairyman who follows a similar practice with his Holsteins, states, "I think when you can't go in an alfalfa pasture field with a mower and rake and get hay you can't expect a dairy cow to get enough so she can give her daily 40 pounds of milk." At Augusta, under this system, the carrying capacity ranged from 122 to 142 cow-days per acre, using a pure-bred Guernsey herd, and gross returns from the alfalfa were as large as or larger than from any other combination of haying and grazing.

GRAZING THE FIRST CUTTING

It was thought that pasturing off the first growth of alfalfa and cutting the second for hay might have a place in a system of management where cows were transferred from one field to another. In the trials of this practice good pasture returns were secured, ranging from 77 to 96 cow-days per acre for the latter part of May and most of June. However, the hay produced afterwards was inferior and weedy, the cows letting many weeds grow which a mower would have cut.

TABLE 4.—*Alfalfa pasture management experiment.*

Method of handling	Year	Yield, lbs. air-dry hay per day		Cow-days pasture per acre	Milk produced per acre while cows were on pasture, lbs.	Value of milk testing 4.6%	Grain fed to cows while on pasture, lbs.	Cost of grain	Cash crop value of hay	Gross returns, i.e., cash value of hay per acre plus value of milk produced on pasture less cost of grain fed to cows on pasture*
		First cutting	Second cutting							
Continuous grazing	1931	—	—	66	2,224	$27.80	556	$7.17	—	$20.63
	1932	—	—	142	4,033	40.81	432	4.32	—	36.49
	1933	—	—	122	3,628	36.71	434	4.34	—	32.37
Grazed 1st cutting; 2nd cutting for hay	1931	—	200	78	2,717	33.96	679	8.76	$1.20	26.40
	1932	—	1,931	77	2,409	24.37	None	0.00	5.79	30.16
	1933	—	1,142	96	1,744	17.65	None	0.00	4.57	22.22
1st cutting for hay; 2nd cutting grazed	1931	2,600	—	30	1,087	13.59	271	3.50	15.60	25.69
	1932	3,982	—	111	2,920	29.55	730	7.30	11.95	34.20
	1933	3,435	—	80	2,202	22.28	500	5.00	13.74	31.02
Harvested for hay, 2 cuttings	1931	2,190	411	—	—	—	—	—	15.61	15.61
	1932	3,589	2,510	—	—	—	—	—	18.30	18.30
	1933	3,570	1,088	—	—	—	—	—	18.82	18.82

*Grain prices: 1931, $1.29 per cwt.; 1932, $1.00 per cwt.; 1933, $1.00 per cwt. Hay prices: 1931, $12.00 per ton; 1932, $6.00 per ton; 1933, $8.00 per ton. Milk prices: 1931, $1.29 per cwt.; 1932 and 1933, 22c per lb. for butter fat.

GRAZING SECOND CUTTING ALFALFA

One of the most common farm practices is to take the first cutting of alfalfa for hay and pasture the subsequent growth. A farm following this practice might have abundant spring and early summer pasture from permanent grass which, for so much of Michigan, is nonproductive when the dry hot weather comes. Some farmers have a sufficient acreage of alfalfa so the first cutting will ordinarily meet all their hay requirements leaving the second cutting for summer pasture and for sale of hay when there is more pasture than is needed.

This system worked well in the Augusta trials. The first cutting of hay was of good quality and its removal controlled most of the annual weeds; the second gave pasture in July and August when there was no grass pasture and without alfalfa the stable feeding of hay and summer silage would have been necessary. Even in 1932, when summer rainfall above normal made possible the production of 111 cow-days of pasture per acre from second-growth alfalfa, there was essentially no July or August grazing from the ordinary permanent grass pastures.

ENDURANCE OF PASTURED ALFALFA

It is not the intention here to compare returns from pastured alfalfa with those from alfalfa cut for hay. Both pasture and hay are needed, for there must be winter forage as well as summer forage. The paddock cut for hay twice each season was used as a check on the condition of stand of the pastured alfalfa. To give the alfalfa in those paddocks being grazed to capacity a chance to recuperate before winter, grazing on them was generally discontinued by September 1. Until the spring of 1934 there appeared to be no great difference in the condition of the alfalfa under each treatment. The stand cut for hay was probably somewhat cleaner than the others and the alfalfa grazed continuously appeared a little less vigorous than did the alfalfa in the other paddocks. Where the second cutting was pastured off it will be noted (Table 3) that the first cutting for hay yielded as much in 1933 as did the first cutting from the area used exclusively for hay.

September 1 was rather arbitrarily set as the date to discontinue grazing because this month in Michigan is the time when alfalfa makes its fall storage of root reserves and close grazing or mowing in September is injurious to the alfalfa. This was demonstrated at Augusta when, in the fall of 1933, the cows pasturing the alfalfa from which a first cutting had been taken for hay (area No. 3) were left on it until September 13. The winter of 1933–34 thinned out all the alfalfa, including that cut only for hay, so much that the stands were no longer considered useful. However, plat No. 3, for 3 years fully equal to the hay plat when grazing was stopped September 1, was injured most of all when it alone was closely pastured to September 13.

A more detailed study of fall clipping and grazing is underway at East Lansing which has given preliminary results supporting the belief that mowing or close grazing alfalfa in September is decidedly injurious to the vigor of the crop. This need not necessarily indicate

that all alfalfa pasturage must stop by September 1 for hay meadows may be available on which cows can be grazed at the rate of 1 animal on 3 to 5 acres, in which case serious injury to the alfalfa is unlikely. In fact Michigan farmers using alfalfa for pasture do continue to use it moderately throughout the fall months with success.

It will be noted that the alfalfa used in the Augusta trials lasted 4 years, 1 for hay and 3 under the different grazing practices. The very severe winter of 1933–34 killed the alfalfa sooner than will generally be the case. Three farmers reported having pastured the same stands of alfalfa 10 years and stated that they were still pretty good pastures. The average reported by the group of 35 farmers, however, was 3.4 years, the usual range being 2 to 4 years, but these figures do not quite give the whole story for many of these farmers harvested their alfalfa only for hay for 1, 2, or more years before using it for pasture. There is much farm opinion in Michigan to support the contention that if alfalfa is pastured judiciously, avoiding very close grazing at all times and permitting as much fall growth as is secured in hay fields, the pasturing will not prove materially harder on it than harvesting the crop exclusively for hay.

THE PROBLEM OF BLOAT

We are concerned not merely with injurious effects which grazing alfalfa may have on the stand but also with possible dangers to the livestock. The bugaboo of the farmer pasturing cattle or sheep on alfalfa is bloat. Many farmers using the crop for pasture have experienced losses, occasionally severe ones. Likewise, bloat losses have been reported on sweet clover, red clover, white clover, soybeans, and rye. Since information on bloat is largely empiric, general farm observations furnish about as reliable information as we have on this problem. Of farmers questioned on bloat, 19 out of 35 reported losses on alfalfa pasture. However, only one had discontinued the use of the crop as pasture because of bloat losses. Nearly all of these men attributed their difficulties to "slip-ups" in management which had permitted the animals to become excessively hungry. When precautions were carefully adhered to, the general opinion of these men was that extra returns from pasturing alfalfa outweighed its dangers.

The most common precautions for the avoidance of bloat were designed to keep the animals from working up too big an appetite and included (a) a full feed for the animals before first being turned on the alfalfa, (b) avoidance of grazing the first new growth, (c) keeping the stock on alfalfa pasture constantly once it was started on it, and (d) the providing of water and salt in or very near the field at all times. Another precaution is that certain animals appear unduly susceptible to bloat and, once discovered, should be kept off alfalfa pasture entirely.

SUMMARY

Experiments at Augusta, Michigan, and the summarized opinions of 35 farmers experienced in pasturing alfalfa are drawn on for information on the utilization of this crop for grazing purposes.

Alfalfa is a more desirable pasture crop than sweet clover in the opinion of nearly all of these farmers, an opinion which is supported by experimental evidence at Augusta. The advantages of alfalfa lay in greater carrying capacity, longer life, longer grazing season, and higher palatability.

Alfalfa has also proved superior to the usual permanent grass pastures on upland Michigan soils because of greater productivity and continued growth during hot dry periods of the summer when grasses were relatively non-productive.

In the Augusta experiments alfalfa pastured continuously proved productive as did that on which the first cutting was taken for hay and the subsequent growth pastured. Pasturing the first growth and harvesting the second for hay was less desirable on account of the annual weed growth in the hay and the fact that this system fails to take full advantage of alfalfa's drought resistance.

The heavy grazing of alfalfa in September proved injurious. Alfalfa on which heavy grazing was discontinued by September 1 came through each winter in nearly as good condition as that from which two cuttings of hay had been removed each season.

Some individual farmers reported having pastured the same stand of alfalfa for 10 years, the average for a group from widely distributed Michigan locations being 3.4 years.

The danger of bloat with cattle or sheep pasturing on alfalfa is prevalent. Most common precautions employed by Michigan farmers to avoid it are (a) to give animals a full feed before first turning them on alfalfa pasture, (b) to keep stock off the first new growth, (c) to keep stock on alfalfa pasture constantly once started on it, and (d) to provide water and salt in or very near the field at all times.

REGISTRATION OF VARIETIES AND STRAINS OF OATS, VI[1]

T. R. STANTON[2]

THE last report on the registration of improved oat varieties was published in 1931.[3] No varieties were submitted for registration in 1932 and 1933. The improved varieties of spring oats approved for registration in 1934 are as follows:

Group and Varietal Name	Registration No.
Midseason white:	
Lenroc	80
Rusota	81
Spooner	82

Information on description and performance of these varieties, on which approval for registration is based, is summarized herein for the benefit of those interested in the production of better oats by growing improved varieties.

LENROC, REG. NO. 80

Lenroc (C. I. no. 3205) was originated as a plant segregate from a cross of Great American (Silvermine type) X Cornellian (Reg. No. 50) made in 1918 by W.T. Craig at Ithaca, N. Y. It was subsequently developed by the Department of Plant Breeding, College of Agriculture, Cornell University, by H. H. Love and W. T. Craig in cooperation with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Lenroc is being multiplied for introduction to farmers in 1935. Application for its registration was made by the Department of Plant Breeding, Cornell University.

Lenroc is a midtall to tall, midseason white oat, with equilateral panicle. The kernels (caryopsis with hull) are similar in conformation to those of the Cornellian parent, but are white; about 50% of the lower florets of the spikelets carry a slightly twisted, semi-geniculate awn.

The superior characters of Lenroc are high yield and white kernels. It is the equal of Cornellian in productiveness, and in sections where there is objection to the gray kernels of Cornellian, Lenroc should replace it.[4]

Lenroc has been tested in replicated rod rows at Ithaca for 11 years. The annual and average yields of Lenroc and Cornellian are given in Table 1.

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[1]Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 6, 1934.

[2]Senior Agronomist in Charge of Oat Investigations, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1934 Committee on Varietal Standardization and Registration charged with the registration of oat varieties.

[3]STANTON, T. R. Registration of varieties and strains of oats, V. Jour. Amer. Soc. Agron., 23:1013–1017. 1931.

[4]The performance and probable value of Lenroc also are discussed briefly in the Report of the Chief of the Bureau of Plant Industry, U. S. Dept. of Agriculture, 1934.

TABLE 1.—*Annual and average acre yields of Lenroc and Cornellian oat varieties grown at Ithaca, N. Y., 1924–34.*

Variety	Acre yield, bushels										
	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	Average
Lenroc	79.8	86.4	83.0	81.7	66.8	24.0	66.2	65.5	45.7	28.5	55.3	62.1
Cornellian	76.2	88.2	84.5	76.6	67.2	25.0	64.4	61.4	44.9	28.7	52.1	60.8

RUSOTA, REG. NO. 81

Rusota (N. Dak. No. 20014, and C. I. No. 2343) was originated as a pure line from Green Russian and subsequently developed at the North Dakota Agricultural Experiment Station, Fargo, N. Dak. The original plant selection was made by T. E. Stoa of that institution in 1922, who also submitted the application for registration. Rusota will be distributed to farmers in northeastern North Dakota in 1935.

It is a midseason white variety with equilateral panicles and differs mainly from the Green Russian parent in having white kernels. Its superior characters are high yield, moderate resistance to stem rust, low percentage of hull, and white kernels. In a letter submitting the application Professor Stoa commented on the variety as follows:

> "I believe that it should be pointed out that this variety is recommended particularly for northeastern North Dakota and northwestern Minnesota where best results have been obtained. In sections further south an earlier maturing variety is preferable. In sections where rust may be less common the rust susceptible varieties may do about as well. The variety would class as a midseason but slightly earlier than Victory, averaging at Fargo 85 days to maturity compared with 86 for Victory and 79 for Gopher. In height Rusota averages only slightly shorter than Victory and has a moderately stiff straw."

Rusota has been tested in replicated field plats at several stations. Average acre yields of Rusota as compared with Victory, Rainbow, Gopher, Anthony, and Iogold, all standard improved varieties, are presented in Table 2.

TABLE 2.—*Comparative average yields from field plats of Rusota and leading standard varieties at experiment stations in North Dakota, northwestern Minnesota, and southern Manitoba.**

State or Province and station	Years for which data are presented	Variety and average acre yield, bushels					
		Rusota	Victory	Rainbow	Gopher	Anthony	Iogold
North Dakota:							
Dickinson	1928 to 1934	29.0	28.3	31.3	31.0	—	31.2
Edgeley	1927 to 1932	63.2	49.8	73.3	57.5	—	—
Fargo	1925 to 1932	75.9	68.4	79.1	77.2	—	—
Fargo	1927 to 1932	69.0	62.4	74.6	72.1	72.9	71.6
Langdon	1927 to 1934	64.9	62.3	64.1	51.4	—	—
Mandan	1928 to 1932	37.4	38.2	37.5	36.4	—	39.3
Minnesota:							
Crookston	1927 to 1934	71.4	58.3	64.5	60.1	68.4	—
Manitoba:							
Brandon	1930 to 1933	92.2	81.2	87.9	81.7	—	—

*Data from Mandan, Crookston, and Brandon presented through the courtesy of agronomists in charge of those stations.

TABLE 3.—*Annual and average yields of Spooner and Swedish Select oat varieties grown at the Spooner Substation, Spooner, Wis., 1917 and 1919–32.**

Variety	Acre yield, bushels															
	1917	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	Average, 15-years
Spooner......	61.8	40.6	51.5	6.0	48.1	34.5	26.7	41.1	21.9	45.3	45.6	34.6	42.3	19.0	31.5	36.7
Swedish Select	47.5	32.5	40.0	4.7	41.0	29.0	22.5	38.2	17.5	42.7	43.6	36.4	41.2	11.5	28.3	31.8

*Owing to the curtailment of work because of the World War no varietal experiments were conducted at Spooner in 1918.

SPOONER, REG. NO. 82

Spooner (Wis. No. S-405 and C. I. No. 3165) was originated at the Spooner Substation of the Wisconsin Agricultural Experiment Station as a pure line from Wisconsin No. 8 (Silvermine type). The original plant selection was made by E. J. Delwiche in 1913 under whose direction the variety was subsequently developed. The variety is named in honor of the late U. S. Senator John C. Spooner of Wisconsin. Application for registration of Spooner was made by E. J. Delwiche. The variety was first distributed for growing on farms in Wisconsin in 1924. It is especially well adapted to the light soil types of central and northern Wisconsin.

Spooner is a midseason white variety with equilateral panicles. Its superior characters are high-yielding power on sandy soils, midseason maturity, stiff straw, and drought resistance.

Spooner has been tested in duplicated field plats at the Spooner Substation for 15 years. Table 3 presents the annual and average yields of Spooner as compared with those of Swedish Select (Wis. No. 5), a standard variety, for the years 1917 and 1919–32 at Spooner.

REGISTRATION OF IMPROVED WHEAT VARIETIES, VIII[1]

J. ALLEN CLARK[2]

SEVEN previous reports present the registration of 273 varieties of wheat. There were no registrations in 1933. In 1932, three varieties were registered, and the previous registration was referred to as in former years.[3]

Varieties approved for registration in 1934 are as follows:

Varietal Name	Registration No.
Relief	274
Rio	275
Rex	276
Thatcher	277
Sturgeon	278

RELIEF, REG. NO. 274

Relief (Utah 43e21, C. I. No. 10082) was produced by the Utah Agricultural Experiment Station from a cross between Hussar (female) and Turkey (male). The cross was made in 1925 and the selection from which Relief descended was made in 1928. The breeder, D. C. Tingey, applied for its registration.

Relief is a hard red winter wheat, resistant to most of the physiologic forms of bunt occurring in Utah. Relief was first grown in replicated nursery rows in 1929, in plat experiments in 1930, and commercially since 1931. The comparative data upon which registration is based are shown in Table 1.

TABLE 1.—*Comparative yields of Relief and other winter wheats grown in nursery and plat experiments at Newton, Utah.*

Variety	Yield in bushels per acre					Average	Percentage of Utah Kanred
	1929	1930	1931	1932	1933		
			Nursery Experiments				
Relief (new)	49.3	36.3	33.3	32.6	19.0	34.1	110.0
Utah Kanred	38.5	35.5	38.4	22.5	20.0	31.0	100.0
Goldcoin	37.9	35.8	26.1	7.3	10.3	23.5	75.8
			Plat Experiments				
Relief (new)	—	34.7	36.8	27.6	29.1	32.1	111.1
Utah Kanred	—	30.9	36.2	22.2	26.2	28.9	100.0
Goldcoin	—	21.8	28.8	20.0	20.7	22.8	78.9

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 6, 1934.

[2]Senior Agronomist, Wheat Investigations, U. S. Dept. of Agriculture. Member of the 1934 Committee on Varietal Standardization and Registration of the Society charged with the registration of wheat varieties.

[3]CLARK, J. ALLEN. Registration of improved wheat varieties, VII. Jour. Amer. Soc. Agron., 24:975–978. 1932.

TABLE 2.—*Comparative smut data from Utah and from regional smut nurseries, 1932.*

Location	Variety						
	Relief	Utah Kanred	Gold-coin	Oro	Ridit	Hussar	Hybrid 128
	Utah Experiments						
Paradise	0.6	60.0	80.1	—	—	—	—
Clarkston	0.0	43.6	—	—	—	—	—
Wellsville	0.0	15.3	52.6	—	—	—	—
Newton	0.0	5.1	37.5	—	—	—	—
North Logan	0.1	34.5	76.0	—	—	—	—
Average	0.1	31.7	61.6	—	—	—	—
	Regional Experiments						
Newton, Utah	1.4	—	—	10.1	7.6	0.0	41.6
Moscow, Idaho	5.9	—	—	17.2	16.4	10.3	95.7
Felt, Idaho	3.0	—	—	3.5	2.2	3.5	65.2
Rockland Bench, Idaho	1.6	—	—	3.3	4.5	1.0	50.8
Pendleton, Oreg.	0.9	—	—	9.7	9.7	2.2	92.5
Moro, Oreg.	0.2	—	—	1.5	4.4	1.5	72.0
Corvallis, Oreg.	10.0	—	—	3.2	7.0	12.4	65.5
Pullman, Wash.	32.8	—	—	4.4	2.6	39.0	88.0
Lind, Wash.	14.0	—	—	0.0	0.0	13.4	25.0
Tucson, Ariz.	0.8	—	—	0.4	1.2	0.0	77.0
Average	7.1	—	—	5.3	5.6	8.3	67.3

RIO, REG. NO. 275

Rio (C. I. No. 10061) was developed from cooperative experiments between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Oregon Agricultural Experiment Station at the Sherman County Branch Station, Moro, Oreg. Rio is the result of a selection made in 1920 and was entered in the plat experiments at Moro in 1925. It was distributed for commercial growing in 1930. Rio is a smut-resistant variety of hard red winter wheat, being selected from Argentine, C. I. No. 1569, which is a strain of Turkey wheat that has produced high yields at the Moro station.

The comparative data upon which registration is based are shown in Tables 3 and 4.

REX, REG. NO. 276

Rex (C. I. No. 10065), like Rio, was developed in cooperative experiments at the Sherman County Branch Station, Moro, Ore., Supt. D. E. Stephens applying for the registration of both varieties. Rex is the result of a cross between White Odessa (female) and Hard Federation (male) made in 1921. The selection, made in 1926, was first included in nursery experiments in 1929 and in plats in 1930. It was distributed for commercial growing in 1933. Rex is a soft white winter wheat with awnleted spikes and brown glumes. Its superior characters

TABLE 3.—*Annual and average yields of Rio and two other winter wheat varieties at Moro and Pendleton, Oreg.*

Variety	Yield in bushels per acre										Av.	Percentage of Ridit
	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934		
Moro, Oreg., Three 1/20-acre Plats												
Rio (new)..	25.3	28.9	40.7	41.5	15.7	16.4	13.7	12.4	16.7	18.2	23.0	112.7
Kharkof.	27.4	27.0	37.9	40.7	14.4	16.3	15.1	14.5	18.0	18.5	23.0	112.7
Ridit...	25.5	23.5	33.7	34.6	13.9	16.3*	14.5	10.1	17.2	14.2	20.4	100.0
Pendleton, Oreg., 3 Protected 16-foot Rows												
Rio (new)..	—	—	—	—	40.3	34.1	30.5	38.6	41.1	31.8	36.1	114.6
Hybrid 128....	—	—	—	—	36.6	34.6	29.9	34.2	38.4	26.4	33.4	106.0
Ridit...	—	—	—	—	36.6	30.4	29.3	28.8	40.5	23.1	31.5	100.0

*Yield of Kharkof substituted.

TABLE 4.—*Average percentages of smut on Rio,* Rex, and other wheats in uniform bunt nurseries in the western states in the years 1932 to 1934, inclusive.*

Variety	1932, 9 stations	1933, 7 stations	1934, 5 stations	3 years, 21 experiments
Rio (new)...............	6.1	7.1	3.3	5.8
Ridit.....................	6.2	12.3	4.4	7.8
Rex (new)...............	14.5	26.4	16.9	19.0
Albit.....................	18.8	29.5	20.8	22.8
Kharkof.................	50.1	44.5	56.1	49.7
Hybrid 128..............	72.0	—	85.7	—

*Further information on Rio wheat is given in Oreg. Agr. Exp. Sta. Bul. 308.

are high yield, early maturity, and resistance to lodging, shattering, and smut. The data on smut resistance and yield are shown in Tables 4 and 5, respectively.

THATCHER, REG. NO. 277

Thatcher (Minn. No. 2303, C. I. No. 10003) was developed in cooperative experiments by the Minnesota Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. It is the result of a cross between Marquis x Iumillo (female) and Marquis x Kanred (male) made in 1921 at University Farm, St. Paul, Minn. The selection resulting in Thatcher was made in 1925 and the strain entered the plat experiments in 1929 and the variety was distributed for commercial growing in 1934. Thatcher is an awnleted, hard red spring wheat. Its superior characters are high yields, early maturity, stiff straw, stem rust resistance, and high milling and baking qualities.

The yields upon which registration is based are shown in Table 6.

TABLE 5.—*Annual and average acre yields of Rex and two other winter wheats at Pendleton and Moro, Oreg.*

Station and variety	Yield in bushels per acre						Average	Percentage of Hybrid 128
	1929	1930	1931	1932	1933	1934		
				3 Protected 16-foot Rows				
Pendleton:								
Rex (new).	39.8	45.2	40.1	45.1	43.6	31.2	40.8	121.1
Hybrid 128	36.6	34.6	32.1	34.2	38.4	26.4	33.7	100.0
Albit	32.1	33.9	30.7	38.0	46.2	26.3	34.5	102.4
				4 1/53-acre Plats				
Pendleton:								
Rex (new).	—	—	41.2	41.8	40.2	28.7	38.0	104.4
Hybrid 128	—	—	37.3	38.4	42.4	27.4	36.4	100.0
Albit	—	—	33.9	36.9	39.8	27.4	34.5	94.8
				3 Protected 16-foot Rows				
Moro:								
Rex (new).	—	18.3	11.9	15.9	—	19.0	16.3	103.2
Hybrid 128.	—	16.4	13.5	19.4	—	13.7	15.8	100.0
Albit	—	13.7	9.3	10.0	—	14.2	11.8	74.7
				3 1/20-acre Plats				
Moro:								
Rex (new)	—	13.0	17.1	10.2	16.9	22.2	15.9	98.8
Hybrid 128...	—	18.3	11.4	9.2	20.0	21.7	16.1	100.0
Kharkof (C. I. No. 8249). .	—	16.3	15.1	14.5	18.0	18.5	16.5	102.5

TABLE 6.—*Comparative yields of Thatcher and other hard red spring wheats at Crookston and Morris, Minn.**

Variety	Yield in bushels per acre					Average	Percentage of Marquis
	1929	1930	1931	1932	1933		
			Crookston				
Thatcher (new)..	33.3	34.4	35.7	19.7	21.7	29.0	119.3
Ceres...	28.6	31.0	35.2	23.8	23.3	28.4	116.9
Marquis	20.5	33.0	29.4	18.3	20.3	24.3	100.0
			Morris				
Thatcher (new)..	24.2	33.9	26.3	13.6	—	24.5	111.9
Ceres.... ..	19.7	30.6	24.8	20.6	—	23.9	109.1
Marquis ..	19.0	29.5	20.7	18.4	—	21.9	100.0

*For further information on Thatcher wheat see Report of the Fourth Hard Spring Wheat Conference, 1934 (Mimeographed); and The Minn. Seed Grower, 7. Feb. 1934.

STURGEON, REG. NO. 278

Sturgeon (Wis. No. 274, C. I. No. 11703) was produced by the Wisconsin Agricultural Experiment Station (Peninsular Branch) at Sturgeon Bay, Wis. It is the result of a cross between Progress (female) and Marquis (male) made in 1924. The selection resulting in

Sturgeon was made in 1927. It was first included in the plat experiments in 1931 and was distributed for commercial growing in 1934 The breeder, E J. Delwiche, applied for its registration

Sturgeon is a high yielding, early maturing, rust-resistant, hard red spring wheat It is awned and has white glabrous glumes and short hard red kernels resembling Marquis more than Progress The milling and baking qualities are better than Progress The comparative data upon which registration is based are shown in Table 7.

TABLE 7 —*Comparative yields and milling and baking data on Sturgeon and other wheats grown at the Peninsular station, Sturgeon Bay, Wis.*

Year	Yield, bu. per acre	Flour yield %	Loaf volume, cu in	Water absorption %	Bread per bbl.-lbs
	Sturgeon (new)				
1931	10 6	70 9	199	63 0	293
1932	10 8	70 0	190	64 1	295
1933	29 3	73 1	181	64 1	295
1934	19 5	—	—	—	—
Average	17 6	71 3	190	63 7	294
Percentage of Marquis	118 9	102 9	97 4	99 7	99 7
	Progress				
1931	6 7	73 5	148	59 9	287
1932	10 7	72 7	116	56 2	280
1933	25 9	71 5	118	58 3	284
1934	[illegible]	—	—	—	—
1931	9 5	69 0	204	63 6	294
1932	10 8	68 0	193	64 1	295
1933	21 5	70 8	189	64 1	295
1934	17 2	—	—	—	—
Average	14 8	69 3	195	63 9	295

BOOK REVIEW

STATISTICAL METHODS FOR RESEARCH WORKERS

By R. A. Fisher. Edinburgh: Oliver & Boyd. Ed. 5. XIII+319 pages and supplementary tables. Illus. 1934. 15 / net.

The first edition of this important work, which has been responsible for a marked change in the methods of analyzing experimental data, appeared in 1925 and contained 239 pages. The fifth edition, published during the last months of 1934, contains 319 pages. Thus in the four last editions there have been added 80 pages of new material in addition to about 10 pages that were rewritten and first appeared in the fourth edition. The fact that five editions have been produced in a little less than 10 years speaks highly of the popularity of the book and shows especially the author's desire to keep each edition up to date by incorporating the latest findings of statistical research applicable to biological investigation.

The differences between the fourth and fifth editions consist of about 12 pages of additional text, two further references to sources, and a continuation of the bibliography of the author's writings since 1931.

No one can justly accuse Dr. Fisher of verbosity in these 12 pages of text for in them he discusses a correction for continuity, gives the exact test of significance for 2 x 2 tables, provides relatively simple adjustments for omitting, without laborious computing, one or more variates from regression equations after they have been included in calculations, and an enlargement of the methods of applying appropriate tests of significance to deviations from regression formulae. In most instances examples of the methods are included. No doubt all of these additions will be welcomed by those investigators who have found the methods given in previous editions of value for interpreting data. (F. Z. H.)

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"THE HUMUS FRONT"

WE are indebted to a reader of the JOURNAL for the following comments and translations on the subject of "humus economy":

"Among the various fronts upon which many European countries are fighting in order to meet the new situations which constantly arise because of growing economic difficulties, the new humus front deserves notice from soil scientists and agronomists.

"A recent issue (No. 16, 1934) of the *Landsberger landwirtschaftliches Nachrichtenblatt*, published by the Prussian Agricultural Experiment Station at Landsberg, carries the following editorial, only a part of which is translated here.

"'HUMUS ECONOMY

THE GERMAN SOIL

"'The basis for the reduction of our crop yields, in spite of increasing use of artificial fertilizers, is found only in the increasing lack of humus in our German soils, because the destruction of humus in soil is hastened through the addition of artificial fertilizers, without sufficient provision being made for a proper supplementation of the organic matter. The result of this is that the "old soil force" disappeared. The system of fallowing, which was looked upon as a basis for bringing about abundant plant development and a proper utilization of mineral substances, does not answer the purpose, under these conditions. A healthy humus economy forms the surest basis both for agriculture and animal husbandry. The use of mineral fertilizers promises full benefit only when the soil is sufficiently enriched in humus.'

"The *Deutsche landwirtschaftliche Presse* also devotes an issue (Nov. 10, 1934) to the humus question. Here, the leading article is one by Prof. G. Ruschmann on 'German Nutrition from Its Own Soil, a Question of Healthy Humus Economy.' This is followed by a series of papers by prominent agricultural workers, including Prof. Roemer, Prof. Kappen, and others, dealing with such subjects as 'Assuring Crop Yields by Planned Humus Economy', 'The Artificial Supply of Humus to Soil', 'Organization of German Humus Economy', 'Twelve Commendements for Treatment of Stable Manure', 'The Dry Year of 1934 as a Lesson in Humus', etc.

"The above journal states in an editorial that, because of the importance of these questions for agriculture, it has been decided, beginning January 1, 1935, to publish monthly articles by prominent workers under the general title of 'Soil Fertility and Humus Economy.'"

THE INTERNATIONAL AGRICULTURAL DIRECTORY FOR 1934

THE third edition of the International Section of the Agricultural Directory, edited by J. W. Pincus, has been published by Wm. Grant Wilson of 777 Concord Ave., Cambridge, Mass., and is available at $1 per copy. The directory lists agricultural institutions in 121 countries. An effort has been made to list important agricultural and allied conferences. Also, for the first time, the directory includes a list of national and international organizations doing colonization or other agricultural work.

A FROSTPROOF WHEAT

AT a recent conference of the Scientific-Technical Council of the Commissariat of Soviet Farms in Moscow, Prof. N.V. Tzipin of the Western Siberian Grain Institute reported a successful cross of Agropyron with wheat. In Siberia, there are no varieties of grains that can withstand the cold, and therefore work was started on crossing wheat on the very hardy Agropyron. After four years' experimentation, a hybrid has been obtained which produced 800 wheat grains from one plant and which survived a very severe winter. The plant has many branches or stools and looks like an Agropyron but produces wheat grains.

Prof. Tzipin's report was discussed at some length by plant breeders present and recommendation made to the Commissariat to increase the appropriation for continuing this work, to publish the results in Russian and English, and to send expeditions into western Siberia, the Altai Regions, and Kazakstan and Transcaucasia to make a thorough study of the wild forms of Agropyrons. It was also suggested that a special staff of plant physiologists, geneticists, and phytopathologists should be assigned to this work.

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EFFECTS OF SOIL TYPE AND SOIL TREATMENTS ON THE CHEMICAL COMPOSITION OF ALFALFA PLANTS[1]

A. L. GRIZZARD[2]

IN some portions of the United States, especially in the dairy sections, certain diseases in dairy cattle are associated with mineral deficiencies, particularly phosphorus, in the roughage fed. As these cattle diseases have been observed in Michigan, information concerning the calcium and phosphorus content of alfalfa hay grown in that state on different soils and with various fertilizer treatments was desired in order to determine under what soil conditions deficiencies in the mineral content of alfalfa hay would be found. The protein content of alfalfa is also important from a feeding standpoint. Accordingly, this investigation was undertaken to determine the composition of alfalfa grown on several of the most extensive soil types of the state and to study the effect of limestone and of phosphate and potash fertilizers on the nitrogen, calcium, and phosphorus content of alfalfa grown on these soil types.

REVIEW OF LITERATURE

A great amount of work has been done on the quality of crops as affected by fertilizer treatments and soil conditions. Of the papers reviewed, only those which deal directly with this problem are mentioned. A fairly complete review of the literature may be obtained from the references given.

Alway (1)[3], using clover and alfalfa; Mather (7), working with alfalfa, timothy, and alsike; Sewell and Latshaw (17); Nygard (11) and others at the Montana station (9); Ames and Boltz (2); Eckles and co-workers (3); and Pitman (12), working with alfalfa, found that applications of available phosphorus to phosphorus-deficient soils increased the percentage of the element in the plants.

[1]Contribution from the Soils Department, Michigan State College, East Lansing, Mich. Abstract of a thesis submitted to the Graduate School of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of doctor of philosophy. Published with permission of the Director of the Michigan Agricultural Experiment Station as Journal Article 194 n.s. of the Experiment Station. Received for publication November 8, 1934.

[2]Formerly Assistant in Soils, Michigan State College; now Assistant Agronomist, Virginia Agricultural Experiment Station, Blacksburg, Va. The writer expresses his thanks and appreciation to Dr. C. E. Millar and Dr. C. H. Spurway of the Soils Department of Michigan State College for their kind advice and constructive criticism given during the course of the investigation and in the preparation of this paper.

[3]Figures in parenthesis refer to "Literature Cited," p. 99.

McCool and Weldon (8) found that the amounts of phosphorus and potassium in the sap of red clover grown on muck soil in pots was roughly proportional to the amounts of these constituents in the fertilizers applied.

Fonder (4) reported that the calcium content increased with maturity of the alfalfa plant. Also, the calcium content was considerably higher in the leaves than in the stems. Of the soils studied, those of medium texture produced alfalfa of higher calcium content than did the very light or the heavy soils.

Holtz (5) found the calcium content of red clover to be largely influenced by the calcium content of the soil. The phosphorus content of red clover also correlated closely with the available phosphorus content of the soil.

Ames and Boltz (2) report that additions of calcium and magnesium to the soil in the form of limestone increased the calcium and magnesium content of the alfalfa, but decreased the yield. The percentages of nitrogen, phosphorus, potassium, and calcium were higher in the first cutting of alfalfa, where the yields were larger than in the second cutting.

Acre application of hydrated lime up to 2,000 pounds increased the calcium content of alfalfa, while the potassium content was decreased by applications up to 8,000 pounds, according to Sewell, *et al.* (16). Heavier additions of lime increased the potassium in the plants. Lime application decreased the nitrogen content of alfalfa, while phosphate treatments reduced the percentage of nitrogen, calcium, phosphorus, and potassium.

Reimer and Tartar (13) and Neidig and co-workers (10) report that application of sulfur increased the nitrogen content of alfalfa.

Satala (14) found that alfalfa hay cut in the one-half bloom stage contained more calcium than plants cut at the one-fourth or three-fourth bloom stage. The calcium content of alfalfa decreased with the number of cuttings and was higher in the first cutting than in the second, which, in turn, contained a higher calcium content than alfalfa cut the third time.

EXPERIMENTAL METHODS

The investigation was carried on under both field conditions and in the greenhouse. For the field studies, use was made of the experimental plats in soil fertility conducted by the Soils Section of the Michigan Experiment Station in different sections of the state. The fertilizer was applied in some cases to established stands of alfalfa as a topdressing, while in other instances the fertilizer and lime were applied and worked into the soil before seeding the alfalfa. One or two cuttings only were obtained from some fields before the farmer plowed down the alfalfa in order to continue his system of crop rotation. In other cases several cuttings of alfalfa were taken.

The pot experiments in the greenhouse were conducted in order that the effect of soil treatments on the composition of the alfalfa might be measured under more controlled conditions than pertain in the field.

Another phase of the problem was the comparison of the composition of alfalfa samples taken from 2 selected areas in field plats with the composition of samples taken from 12 areas geometrically located on each plat.

METHOD OF FIELD SAMPLING

In the selection sampling method the entire plat was carefully observed for variations in the plant growth and uniformity of stand, and samples were then taken from two ½ square rod areas decided upon by two persons as representative

of plant growth on the plat. Several handfuls of green plants from each area were combined to make a standard sample from the plat. All samples were placed in paper containers and taken to a large laboratory where they were spread out to dry for 6 weeks.

Alfalfa samples taken in 1930 and 1931 were carefully separated into stems and leaves and the weight of each determined before analyzing.

The moisture, total nitrogen, calcium oxide, and phosphorus pentoxide contents of the alfalfa plants were determined according to the methods outlined in the second edition of the Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists. All analyses were made in duplicate and all results are reported on the oven-dry basis.

The data are presented under the name of each soil type on which studies were conducted. A description of each soil may be obtained from soil survey reports for Michigan.

RESULTS OF FIELD EXPERIMENTS

ISABELLA SANDY LOAM

The acidity of the soil was corrected sufficiently for the growing of alfalfa by the application of 3 tons of limestone to the acre in early June, after the soil had been plowed and worked down. Phosphate and potash fertilizers were drilled about 5 inches deep in the soil the last week in July. Due to deficiency of soil moisture, the alfalfa was not seeded until the first week in August, 1929. A good stand of alfalfa was obtained which produced better than an average crop. The effects of the various soil treatments on the composition of the alfalfa and the ratio of leaves to stems are shown by the data in Tables 1, 2, 3, 4, and 5.

The data in Tables 1 to 5, inclusive, show that the effects of soil treatments on the composition of alfalfa are not entirely consistent for different cuttings and in different seasons. Evidently, factors other than those studied play a great part in determining the chemical composition and ratio of leaves to stems of alfalfa plants. The data, however, warrant the following observations:

1. When taken in the one-half bloom stage, the first cuttings showed a much lower ratio of leaves to stems than the second cuttings. Also, the first cutting in the bud stage was much more leafy than when taken in the one-half bloom stage. The ratio of leaves to stems was not consistently affected by soil treatments. No explanation is offered for the very low ratio of leaves to stems found in the first cutting for 1931.

2. Averages for group treatments show that the nitrogen content of the leaves was approximately double that of the stems in most cases and considerably more than double for the first cutting in 1931. All soil treatments containing limestone tended to increase the nitrogen content of both leaves and stems of alfalfa, as compared to that of alfalfa grown on untreated soil. The increases in nitrogen content were least consistent in the results for the first cutting in 1931. In some instances, increasing quantities of limestone applied tended to increase nitrogen content of the alfalfa.

3. The data as a whole showed the calcium content of alfalfa leaves to be from two to three times as great as that of the stems. Applica-

TABLE 1.—*Effect of increasing limestone applications with superphosphate and muriate of potash to Isabella sandy loam soil on the partial composition of alfalfa cut in the bud stage in 1930.**

Plat No.	Limestone, lbs.	Ratio of leaves to stems	Percentage of Water: Stems	Water: Leaves	N: Stems	N: Leaves	CaO: Stems	CaO: Leaves	P_2O_5: Stems	P_2O_5: Leaves
	Limestone Alone									
1	None	1.46	10.2	9.5	1.43	2.81	2.03	4.75	0.74	0.82
2	552	1.36	11.1	10.0	1.54	2.81	1.83	4.86	0.76	0.82
3	2,000	1.46	10.8	10.0	1.72	3.08	1.83	4.30	0.68	0.79
4	6,000	1.72	12.4	10.6	1.86	3.47	2.03	5.16	0.60	0.84
5	12,500	1.43	11.8	10.9	2.22	4.04	1.99	5.28	0.69	0.86
	390 lbs. 20% Superphosphate									
6	None	1.43	11.2	10.4	1.56	2.68	2.03	5.22	0.74	0.79
7	552	1.35	9.8	10.2	1.55	2.84	1.97	5.09	0.72	0.78
8	2,000	1.44	9.8	9.3	1.53	2.92	2.04	4.65	0.74	0.83
9	6,000	1.43	9.4	9.3	1.86	3.26	1.93	4.71	0.70	0.83
10	12,500	1.48	10.9	10.1	2.17	3.82	1.76	5.49	0.60	0.73
	186 lbs. Muriate of Potash									
11	None	1.43	9.9	11.8	1.59	2.45	1.65	3.81	0.57	0.61
12	552	1.20	9.9	10.8	1.69	2.81	1.81	4.14	0.53	0.71
13	2,000	1.30	10.0	12.7	1.89	3.60	1.39	3.40	0.60	0.61
14	6,000	1.17	10.4	9.5	1.70	2.55	1.65	4.29	0.64	0.60
15	12,500	1.54	10.7	9.9	2.14	3.94	1.23	3.47	0.50	0.67
	234 lbs. 20% Superphosphate and 94 lbs. Muriate of Potash, or 390 lbs. 0–12–12 Fertilizer									
16	None	1.25	13.2	11.3	1.55	2.84	1.72	3.61	0.80	0.85
17	552	1.31	13.9	11.8	1.69	3.99	1.64	3.77	0.72	0.81
18	2,000	1.54	13.2	12.3	2.07	4.14	1.57	3.62	0.64	0.88
19	6,000	1.38	12.4	12.8	1.61	3.16	1.71	4.41	0.64	0.78
20	12,500	1.19	12.8	13.0	1.91	3.51	1.63	4.78	0.55	0.66
	Averages									
	No limestone	1.39	11.1	10.8	1.53	2.69	1.86	4.35	0.71	0.77
	Limestone alone	1.49	11.5	10.4	1.84	3.35	1.92	3.90	0.68	0.83
	Limestone + phosphorus	1.42	9.9	9.7	1.78	3.21	1.92	4.99	0.69	0.79
	Limestone + potash	1.30	10.7	10.8	1.86	3.23	1.52	3.83	0.57	0.65
	Limestone + phosphorus and potash	1.35	13.1	12.5	1.82	3.70	1.64	4.14	0.64	0.78

TABLE 2.—*Effect of increasing limestone applications with superphosphate and muriate of potash to Isabella sandy loam soil on the partial composition of alfalfa, first cutting for hay, one half-bloom stage, 1930.**

Plat No	Limestone, lbs	Ratio of leaves to stems	Percentage of							
			Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
	Limestone Alone									
1	None	0.94	8.3	10.3	1.35	2.26	2.57	7.11	0.97	0.90
2	552	0.95	8.5	10.6	1.49	2.95	2.07	6.29	0.66	0.85
3	2,000	0.95	8.9	10.7	1.54	2.87	2.19	6.77	0.79	1.03
4	6,000	0.99	8.6	11.1	1.79	3.34	1.92	5.78	0.83	1.03
5	12,500	1.21	9.6	11.5	1.96	3.50	2.04	6.11	0.59	0.88
	390 lbs. 20% Superphosphate									
6	None	0.88	9.1	10.1	1.16	2.32	2.43	6.61	0.93	1.00
7	552	1.09	9.2	10.0	1.63	3.12	2.09	6.37	0.63	0.88
8	2,000	0.93	9.4	9.6	1.47	3.18	1.88	6.54	0.88	1.00
9	6,000	1.07	10.0	10.9	1.84	3.56	1.94	5.92	0.59	0.88
10	12,500	0.81	8.4	10.3	1.55	3.03	1.81	5.59	0.62	0.84
	186 lbs. Muriate of Potash									
11	None	0.83	9.5	10.9	1.18	2.35	2.12	5.51	0.96	1.01
12	552	0.88	9.4	10.3	1.59	2.90	2.05	5.37	0.67	0.79
13	2,000	1.01	10.0	10.4	1.75	3.22	1.67	4.20	0.63	0.74
14	6,000	0.83	9.0	10.4	1.54	3.23	1.58	4.06	0.53	0.72
15	12,500	1.12	9.1	10.2	1.71	3.37	1.71	4.64	0.36	0.59
	234 lbs. 20% Superphosphate and 94 lbs. Muriate of Potash, or 390 lbs. 0–12–12 Fertilizer									
16	None	0.90	9.6	10.5	1.55	2.39	2.24	6.09	0.92	1.00
17	552	1.05	9.2	10.5	1.27	3.27	1.98	5.68	0.48	0.74
18	2,000	0.93	9.0	11.5	1.31	2.78	1.93	5.65	0.68	0.80
19	6,000	1.06	9.4	11.1	1.57	3.37	1.74	4.83	0.62	0.76
20	12,500	1.01	9.6	12.1	1.60	3.34	1.91	5.26	0.49	0.69
	Averages									
No limestone		0.89	9.1	10.4	1.31	2.33	2.34	6.33	0.95	0.98
Limestone alone		1.03	8.9	10.9	1.69	3.15	2.06	6.24	0.72	0.95
Limestone + phosphorus		0.97	9.3	10.2	1.62	3.22	1.93	6.11	0.68	0.90
Limestone + potash		0.96	9.4	10.3	1.64	3.18	1.75	4.57	0.55	0.71
Limestone + phosphorus and potash		1.01	9.3	11.3	1.44	3.19	1.89	5.36	0.57	0.75

*Results reported on oven-dry basis

TABLE 3.—*Effect of increasing limestone applications with superphosphate and muriate of potash to Isabella sandy loam soil on the partial composition of alfalfa, second cutting for hay, one half-bloom stage, 1930.**

Plat No.	Limestone, lbs.	Ratio of leaves to stems	Percentage of Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
	Limestone Alone									
1	None	1.21	11.2	11.1	1.72	3.25	2.14	4.44	0.91	0.94
2	552	1.67	11.5	11.4	1.95	3.93	1.89	3.98	0.71	0.77
3	2,000	1.51	11.6	12.9	1.87	3.68	2.02	4.26	0.68	0.79
4	6,000	1.59	12.4	12.5	2.06	4.00	2.09	4.36	0.67	0.75
5	12,500	1.66	12.1	12.8	2.03	4.06	2.13	4.38	0.66	0.69
	390 lbs. 20% Superphosphate									
6	None	1.73	9.6	12.2	1.76	3.65	2.03	4.00	0.92	1.09
7	552	1.68	10.4	12.0	2.06	3.88	2.37	4.90	0.72	0.83
8	2,000	1.61	10.8	10.5	2.32	4.14	2.21	3.93	0.68	0.81
9	6,000	1.71	11.0	11.5	2.06	4.02	2.32	3.85	0.73	0.75
10	12,500	2.03	11.0	11.0	2.06	4.08	2.06	6.66	0.53	0.70
	186 lbs. Muriate of Potash									
11	None	1.15	9.7	11.5	1.77	2.94	2.12	4.87	0.94	1.09
12	552	1.47	10.8	12.0	1.87	3.81	1.86	3.77	0.65	0.76
13	2,000	1.39	11.0	12.1	1.96	3.50	2.14	4.41	0.65	0.71
14	6,000	1.81	11.2	12.8	2.16	4.01	1.67	3.65	0.70	0.79
15	12,500	1.77	11.4	11.9	2.15	4.11	2.24	4.02	0.53	0.68
	234 lbs. 20% Superphosphate and 94 lbs. Muriate of Potash, or 390 lbs. 0–12–12 Fertilizer									
16	None	1.38	11.4	11.3	1.98	3.30	2.25	4.42	0.88	0.95
17	552	1.56	11.4	11.9	1.97	3.88	2.18	4.20	0.67	0.75
18	2,000	1.56	11.5	11.0	1.87	3.53	2.15	4.30	0.57	0.64
19	6,000	1.69	12.0	10.9	2.10	3.94	2.05	4.12	0.63	0.76
20	12,500	1.54	10.9	11.6	2.13	3.69	2.18	4.84	0.51	0.66
	Averages									
No limestone		1.28	10.5	11.5	1.81	3.29	2.14	4.43	0.91	1.02
Limestone alone		1.61	11.9	12.2	1.98	3.92	2.03	4.25	0.68	0.75
Limes......tone+phosphorus		1.76	10.8	11.3	2.13	4.03	2.24	4.84	0.67	0.77
Limestone+potash		1.61	11.1	12.2	2.04	3.86	1.98	3.96	0.63	0.74
Limestone + phosphorus and potash		1.59	11.5	11.4	2.02	3.76	2.14	4.37	0.59	0.70

TABLE 4 —*Effect of increasing limestone applications with superphosphate and muriate of potash to Isabella sandy loam soil on the partial composition of alfalfa, first cutting for hay, one half-bloom stage, 1931* *

Plat No	Limestone, lbs	Ratio of leaves to stems	Percentage of							
			Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
	Limestone Alone									
1	None	0.81	5.7	6.8	1.55	3.41	1.79	3.65	0.72	1.00
2	552	0.64	5.7	7.2	1.81	3.91	1.50	4.34	0.35	0.74
3	2,000	0.69	5.8	7.5	1.62	3.71	1.48	4.27	0.66	0.81
4	6,000	0.67	6.6	8.6	1.69	4.05	1.61	4.90	0.40	0.84
5	12,500	0.57	6.5	8.2	1.74	4.00	1.59	4.16	0.41	0.85
	390 lbs 20% Superphosphate									
6	None	0.65	6.5	8.2	1.57	3.75	1.73	3.35	0.50	0.84
7	552	0.64	6.2	8.4	1.50	3.54	1.58	4.62	0.45	0.78
8	2,000	0.64	6.1	8.2	1.66	3.85	1.45	4.59	0.51	0.80
9	6,000	0.89	6.5	8.4	1.90	4.15	1.70	4.49	0.51	0.86
10	12,500	0.64	6.6	8.6	1.87	3.97	1.51	4.71	0.49	0.85
	186 lbs Muriate of Potash									
11	None	0.72	6.4	7.8	1.49	3.24	1.53	3.46	0.75	1.02
12	552	0.56	6.1	7.6	1.64	4.03	1.44	3.46	0.36	0.74
13	2,000	0.55	6.2	7.9	1.42	3.51	1.53	3.77	0.34	0.73
14	6,000	0.55	6.2	7.9	1.53	3.89	1.23	3.96	0.37	0.77
15	12,500	0.59	6.1	8.1	1.82	3.83	1.29	4.35	0.39	0.72
	234 lbs 20% Superphosphate and 94 lbs Muriate of Potash or 390 lbs of 0–12–12 Fertilizer									
16	None	0.63	6.5	7.8	1.41	3.75	1.37	3.27	0.55	0.99
17	552	0.76	6.8	8.2	1.58	3.87	1.52	4.03	0.37	0.77
18	2,000	0.68	6.6	8.3	1.59	3.66	1.37	4.40	0.35	0.69
19	6,000	0.52	6.5	8.3	1.59	4.00	1.19	4.33	0.40	0.77
20	12,500	0.61	6.5	8.0	1.76	4.06	1.24	3.62	0.42	0.77
	Averages									
No limestone		0.70	6.3	7.6	1.51	3.54	1.61	3.18	0.63	0.99
Limestone alone		0.64	6.2	7.9	1.72	3.92	1.55	4.43	0.46	0.81
Limestone+phosphorus		0.70	6.3	8.4	1.73	3.88	1.56	4.60	0.49	0.82
Limestone+potash		0.56	6.2	7.9	1.60	3.82	1.37	3.89	0.37	0.74
Limestone + phosphorus and potash		0.64	6.6	8.2	1.63	3.89	1.33	4.09	0.39	0.75

*Results reported on oven-dry basis

TABLE 5.—*Effect of increasing limestone applications with superphosphate and muriate of potash to Isabella sandy loam soil on the partial composition of alfalfa, second cutting for hay, one half-bloom stage, 1931.**

Plat No.	Limestone, lbs.	Ratio of leaves to stems	Percentage of							
			Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
	Limestone Alone									
1	None	1.53	8.2	9.9	1.71	3.29	1.77	3.56	0.54	0.59
2	552	1.87	8.6	10.1	1.95	3.78	1.79	3.69	0.36	0.59
3	2,000	1.24	8.0	10.2	2.01	4.11	1.59	4.07	0.37	0.60
4	6,000	1.60	8.0	10.5	2.38	4.22	1.55	3.69	0.39	0.59
5	12,500	1.36	10.5	13.8	1.95	4.03	1.52	4.08	0.37	0.62
	390 lbs. 20% Superphosphate									
6	None	1.34	9.7	11.7	1.80	3.88	1.52	3.59	0.42	0.64
7	552	1.61	9.8	11.9	2.20	4.17	1.79	4.08	0.49	0.65
8	2,000	1.25	10.6	12.5	2.07	4.37	1.49	4.15	0.43	0.64
9	6,000	1.25	10.4	13.8	2.05	4.05	1.67	4.27	0.40	0.60
10	12,500	1.14	11.0	14.0	2.09	4.35	1.44	3.79	0.49	0.72
	186 lbs. Muriate of Potash									
11	None	1.54	9.9	11.2	1.98	3.70	1.66	3.33	0.64	0.70
12	552	1.55	9.3	11.0	2.02	3.98	1.78	3.63	0.42	0.61
13	2,000	1.22	9.3	11.2	2.09	4.01	1.51	3.89	0.39	0.59
14	6,000	1.74	9.9	12.7	2.06	4.19	1.33	3.28	0.43	0.54
15	12,500	1.46	8.9	11.5	2.10	4.11	1.41	3.33	0.42	0.63
	234 lbs. 20% Superphosphate and 94 lbs Muriate of Potash, or 390 lbs. 0–12–12 Fertilizer									
16	None	1.66	7.8	8.7	1.81	3.35	1.93	3.53	0.50	0.57
17	552	1.65	8.9	8.9	1.84	3.90	1.57	3.57	0.39	0.57
18	2,000	1.55	7.6	9.3	2.00	4.02	1.16	2.77	0.38	0.57
19	6,000	1.48	7.9	10.1	2.06	3.88	1.52	3.27	0.40	0.61
20	12,500	1.26	9.4	10.0	2.15	4.16	1.32	2.80	0.39	0.61
	Averages									
No limestone		1.52	8.9	10.4	1.83	3.56	1.72	3.50	0.53	0.63
Limestone alone		1.52	8.8	11.2	2.07	4.04	1.61	3.88	0.37	0.60
Limestone+phosphorus		1.31	10.5	13.1	2.10	4.24	1.60	4.07	0.45	0.65
Limestone+potash		1.49	9.4	11.6	2.07	4.07	1.51	3.53	0.42	0.59
Limestone + phosphorus and potash		1.49	8.5	9.6	2.01	3.99	1.39	3.10	0.39	0.59

tion of limestone alone did not consistently increase or decrease the calcium content of the alfalfa, nor did increasing quantities of limestone alone or with fertilizer. Applications of potash with limestone tended to decrease the calcium content of the plants.

4. Group treatment averages of the data show that alfalfa leaves contained a higher phosphorus content than did the stems. Applications of limestone alone tended to depress the phosphorus content of the plants. Either potash or phosphorus applied with limestone had a depressing effect on the phosphorus content of both stems and leaves of the alfalfa. The phosphorus content of the stems and leaves tended to be higher in the first cutting than in the second cutting. Applications of phosphorus alone or in combination did not increase the phosphorus content of the alfalfa

BROOKSTON SOILS

These soils do not require liming for alfalfa growing. The crops usually grown respond favorably to applications of superphosphate or fertilizers containing a high percentage of phosphoric acid.

Brookston silt loam. —On field 1 the alfalfa was seeded with oats in the spring of 1929 and the fertilizer was applied broadcast on the surface of the soil after the second cutting in the season of 1930, without harrowing to work the fertilizer into the soil. The alfalfa on field 2 was several years old. The fertilizer was applied as a topdressing after the second cutting in the season of 1930. Samples were taken from both fields in 1931. The data are presented in Table 6.

Brookston clay loam.— The alfalfa grown on this soil was seeded in wheat in the spring of 1929 and topdressed after the first cutting for hay in the season of 1930. Samples taken for analytical work were obtained in 1931. The data are presented in Table 7.

Brookston loam.—The field was prepared after corn for the seeding of wheat in which the alfalfa was seeded the spring of 1930. The data are given in Table 8.

The data in Tables 6, 7, and 8 show that the first cutting of alfalfa grown on Brookston soils had a much lower ratio of leaves to stems than the second cutting. This result is in agreement with that from Isabella sandy loam. With one exception, fertilizer treatments decreased the ratio of leaves to stems on Brookston clay loam, but increased it in the second cutting on Brookston loam.

The nitrogen content of the alfalfa leaves was approximately double that of the stems. The effect of fertilizer applications on nitrogen content of both leaves and stems was inconsistent.

For all treatments the calcium content of the leaves was from two to three times that of the stems. No consistent variation in the calcium content of the alfalfa was observed as a result of fertilization.

On the whole, fertilization increased the phosphorus content of the alfalfa, although there are several cases where this result was not found

MIAMI SILT LOAM

Miami silt loam is of medium fertility and alfalfa growing on this soil usually responds well to applications of fertilizer containing a high percentage of phosphoric acid and a moderate percentage of potash.

TABLE 6.—*Effect of various fertilizer applications to Brookston silt loam soil on the partial composition of alfalfa, cut in the one-half bloom stage, 1931.**

Plat No.	Treatment	Ratio of leaves to stems	Percentage of							
			Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
			First Cutting, Field 1							
1	None	0.59	8.2	10.9	1.70	3.88	1.51	6.49	0.30	0.57
2	250 lbs. 0–20–20	0.63	7.9	10.0	1.91	3.96	1.52	5.61	0.41	0.57
3	500 lbs 0–20–20	0.59	9.8	10.0	2.20	4.02	1.42	5.64	0.50	0.55
4	500 lbs. 0–0–20	0.51	7.5	10.1	1.84	3.94	1.47	5.50	0.30	0.52
5	500 lbs. 0–20–0	0.55	7.2	9.9	2.16	4.00	1.30	5.30	0.57	0.67
			Second Cutting, Field 1							
1	None	1.26	11.0	11.2	1.86	3.46	1.95	4.32	0.40	0.42
2	250 lbs. 0–20–20	1.28	11.6	12.3	1.87	3.88	1.99	5.12	0.41	0.51
3	500 lbs. 0–20–20	1.27	11.5	12.0	1.86	3.84	1.90	4.86	0.57	0.56
4	500 lbs. 0–0–20	1.29	11.1	11.4	1.88	4.05	1.98	4.95	0.39	0.53
5	500 lbs. 0–20–0	1.26	11.3	10.6	1.86	3.99	1.99	4.97	0.59	0.60
			First Cutting, Field 2							
6	None	0.64	8.2	10.2	2.08	3.89	1.57	5.15	0.37	0.57
7	300 lbs. 0–16–0	0.83	8.7	10.3	2.14	3.94	1.47	4.42	0.38	0.56
8	300 lbs. 0–16–8	0.75	8.1	10.1	2.07	4.18	1.61	5.63	0.38	0.62
			Second Cutting, Field 2							
6	None	1.39	7.7	10.4	1.96	4.07	1.99	4.98	0.37	0.58
7	300 lbs. 0–16–0	1.19	7.7	9.8	1.89	4.15	1.80	4.39	0.30	0.49
8	300 lbs. 0–16–8	1.30	7.7	10.2	2.19	4.11	1.85	5.03	0.33	0.53

*Results reported on oven-dry basis.

TABLE 7.—*Effect of various fertilizer applications to Brookston clay loam soil on the partial composition of alfalfa cut in the one-half bloom stage, second cutting for hay, 1931.**

Plat No.	Treatment	Ratio of leaves to stems	Percentage of							
			Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
1	None	1.75	7.1	8.4	2.26	4.47	1.83	4.90	0.30	0.58
2	300 lbs. 0–20–0	1.84	7.3	8.3	2.47	4.45	1.90	4.75	0.47	0.65
3	500 lbs. 0–20–0	1.35	6.7	8.1	2.41	4.66	1.68	4.28	0.46	0.70
4	300 lbs. 0–20–20	1.56	8.0	10.9	2.18	4.37	1.79	5.12	0.33	0.66
5	500 lbs. 0–20–20	1.28	7.7	10.6	2.21	3.43	1.61	4.74	0.40	0.63

*Results reported on oven-dry basis.

TABLE 8.—*Effect of various fertilizer applications to Brookston loam soil on the partial composition of alfalfa cut in the one-half bloom stage for hay in 1931.**

Plat No.	Treatment	Ratio of leaves to stems	Percentage of							
			Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
			First Cutting							
1	None	0.66	6.2	7.4	1.59	4.20	1.69	4.45	0.23	0.55
2	500 lbs. 0–16–0	0.64	6.3	7.7	1.78	4.28	1.75	5.04	0.37	0.64
3	500 lbs. 0–16–20	0.52	6.4	7.5	1.76	3.61	1.50	4.48	0.32	0.61
			Second Cutting							
1	None	1.03	6.3	7.6	1.86	4.01	2.22	5.30	0.35	0.50
2	500 lbs. 0–16–0	1.32	7.1	8.5	2.15	4.11	2.25	5.43	0.39	0.50
3	500 lbs. 0–16–20	1.76	7.3	7.9	2.19	4.13	2.28	4.85	0.37	0.50

*Results reported on oven-dry basis

In the late spring of 1929, corn stubble was plowed down and a good seedbed for alfalfa prepared. The fertilizer was placed on the soil surface with a broadcasting machine and worked well into the soil during the seedbed preparation. A good stand of alfalfa was obtained, the yields being considerably influenced by fertilizer treatments. Samples of the second cutting only were taken for analysis. The data are presented in Table 9

Table 9 shows that on Miami silt loam fertilizer treatments depressed the ratio of leaves to stems and increased somewhat the nitrogen content of alfalfa stems and leaves over that of plants from the no-treatment plats.

The treatment that contained potash markedly depressed the calcium content of alfalfa stems and leaves compared to that of alfalfa which received no treatment. The calcium content of the leaves was double that of the stems.

Alfalfa leaves contained a higher phosphorus content than the stems in all cases. The phosphate plus potash treatment increased the phosphorus content of both stems and leaves over that of plants from the untreated soil

GILFORD LOAM

The plow soil of this soil type is nearly neutral in reaction and the lower subsoil and substrata are highly calcareous. Fertilizers rich in phosphoric acid are beneficial to most crops. The field from which the samples of alfalfa were taken for analysis had been in alfalfa for several years. Fertilizer was applied as a topdressing by means of the fertilizer attachment on a grain drill and it was not worked into the soil. The results are shown in Table 10.

The data presented in Table 10 show that all soil treatments depressed the ratio of alfalfa leaves to stems as compared to that for plants from unfertilized soil.

Taking the nitrogen content of stems and leaves of alfalfa from unfertilized soil as a basis, the phosphate treatment increased the nitrogen content of both stems and leaves; while the phosphate plus potash treatment depressed it somewhat in both the stems and leaves.

Fertilizer lowered the calcium content of stems and leaves, the treatment that contained potash having the greatest depressing effect. The calcium content of the leaves was nearly three times that of the stems.

The phosphorus content of leaves was higher than that of the stems. Both fertilizer treatments increased the phosphorus content of stems and leaves.

EFFECT OF SOIL TYPE BOTH WITH AND WITHOUT LIME AND FERTILIZER TREATMENTS ON THE PARTIAL COMPOSITION OF ALFALFA

Data for all cuttings of alfalfa taken from each soil type and for all fertilizer and lime treatments were averaged to determine what differences might be found in the nitrogen, calcium, and phosphorus

TABLE 9.—*Effect of various fertilizer applications to Miami silt loam soil on the partial composition of alfalfa cut in the one-half bloom stage, second cutting for hay, 1930.**

Plat No.	Treatment	Ratio of leaves to stems	Percentage of							
			Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
1	None....	2.05	11.9	10.9	1.98	3.97	2.08	5.32	0.28	0.46
2	300 lbs. 0–16–0..... ...	1.48	10.9	13.7	2.02	4.15	2.01	5.41	0.29	0.50
3	300 lbs. 0–16–8....... . .	1.61	11.9	13.5	2.11	4.21	1.86	3.38	0.34	0.53

*Results reported on oven-dry basis.

TABLE 10.—*Effect of various fertilizer applications to Gilford loam soil on the partial composition of alfalfa cut in the one-half bloom stage, first cutting for hay, 1931.**

Plat No.	Treatment	Ratio of leaves to stems	Percentage of							
			Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
1	None....................	1.26	8.4	11.0	2.05	3.57	2.28	7.56	0.26	0.38
2	300 lbs. 0–16–0..............	0.97	8.3	10.8	2.15	3.78	2.11	7.43	0.38	0.58
3	300 lbs. 0–16–8..............	0.93	8.0	11.2	1.99	3.64	1.78	7.00	0.38	0.59

*Results reported on oven-dry basis.

content of plants grown on the various soil types. These data are presented in Table 11.

TABLE 11.—*Partial composition of alfalfa grown on different soil types, averaging results for all cuttings from plats receiving various soil treatments.*

Soil type	Percentage of N		Percentage of CaO		Percentage of P_2O_5	
	Stems	Leaves	Stems	Leaves	Stems	Leaves
Brookston silt loam	1.99	4.01	1.69	5.11	0.42	0.55
Brookston clay loam	2.32	4.12	1.75	4.72	0.42	0.66
Brookston loam	1.97	4.04	1.95	4.95	0.36	0.56
Miami silt loam	2.12	4.18	1.94	4.40	0.32	0.52
Gilford loam	2.07	3.71	1.95	7.22	0.38	0.59
Isabella sandy loam	1.80	3.59	1.77	4.43	0.57	0.77
Average	2.05	3.94	1.84	5.14	0.41	0.61

In Table 12 is given the average composition of alfalfa grown on the different soil types without treatments of lime or fertilizer.

TABLE 12.—*Partial composition of alfalfa grown on different soil types, averaging results for all cuttings from plats receiving no lime or fertilizer treatment.*

Soil type	Percentage of N		Percentage of CaO		Percentage of P_2O_5	
	Stems	Leaves	Stems	Leaves	Stems	Leaves
Brookston silt loam	1.90	3.82	1.75	5.23	0.36	0.53
Brookston clay loam	2.26	4.47	1.83	4.90	0.30	0.58
Brookston loam	1.73	4.11	1.95	4.93	0.29	0.53
Miami silt loam	1.98	3.97	2.08	5.32	0.28	0.46
Gilford loam	2.05	3.37	2.28	7.56	0.26	0.38
Isabella sandy loam	1.59	3.08	1.93	4.36	0.75	0.88
Average	1.92	3.80	1.97	5.38	0.37	0.56

The data in Tables 11 and 12 indicate that the heavy soil types, such as Brookston clay loam, tend to give a higher nitrogen content in the alfalfa plants than the lighter soil types, such as Isabella sandy loam, both when fertilized and unfertilized. On the other hand, the lighter soil types tend to give a decidedly higher phosphorus content in the alfalfa plants than the heavy soil types, this being true both in the fertilized and in the unfertilized condition. In the case of calcium, there is a tendency for this element to be decidedly higher in the intermediate soil types, such as the Gilford and Brookston loams, than in either the heavy or light soil types. Apparently, these data indicate that soil type predominates over fertilizer treatments in the composition of alfalfa; although fertilization tends to influence the composition of alfalfa, especially in certain soils.

GENERAL DISCUSSION

A comparison of the analysis of alfalfa cuttings with regard to the ratio of leaves to stems shows that, on the whole, the data are quite inconsistent. It cannot be said that limestone or fertilizer treatments increased or decreased to any appreciable extent the ratio of leaves to stems of alfalfa plants taken from the various soil types under investigation.

Average data (Tables 11 and 12) show that soil treatments tended to increase the total nitrogen content of alfalfa grown on the soil types under investigation and also the phosphorus content, with the exception of the alfalfa grown on Isabella sandy loam in which case a depression of phosphorus content resulted. The data for individual soil types, however, show considerable inconsistency in this regard.

General averages of data indicate that soil treatments decreased the calcium content of the alfalfa. Data are variable, however, for individual soil types, with the exception of that for Gilford loam. Treatments including potash showed a decided tendency to reduce the calcium content of alfalfa on all soils except the Brookston type.

In Tables 11 and 12 it is shown that the heaviest textured soils produced alfalfa containing a higher total nitrogen content with a medium calcium and phosphorus content. Such hays are considered to have an unfavorable balance of digestible nutrients and were produced in regions where nutritional disorders in dairy cattle are known to exist. Alfalfa grown on medium textured soils, such as the Brookston and Gilford loams, was generally high in total calcium, medium in nitrogen, and low in phosphorus. The low phosphorus content of the hay gives an unfavorable nutrient balance. These soils are of widest occurrence in regions where nutritional disorders in cattle are known to occur. On the lighter textured soil, however, such as Isabella sandy loam and Fox sandy loam (Table 13), the phosphorus content of the alfalfa hay is high in comparison with nitrogen and calcium. This condition gives a hay with better nutritive balance. These soils occur in regions where nutritional disorders in dairy cattle are not commonly observed. It appears, therefore, that soil type is an important factor in determining the feeding value of alfalfa hay, and indirectly, the location and extent of nutritional disturbances in dairy cattle.

SYSTEMATIC SAMPLING STUDY

In 1932, a comparative study was made of the random method of sampling previously described with a systematic method of taking samples of alfalfa from field plats for chemical analysis. The plat was divided lengthwise into four strips of equal width for the systematic sampling. From each strip three square-yard areas were harvested, the areas being equidistant from each other and from the sides of the strips. The areas were staggered in respect to the distance from the end of the plat. Sets of samples were taken from Brookston clay loam, Isabella sandy loam, Mancelona gravelly sandy loam, and Fox sandy loam.

A summary of the analytical data obtained from the samples is presented in Table 13. Since only two samples were taken at random,

it is impossible to treat the data statistically. It appears, however, from a consideration of the averages of the percentages of the elements determined in the plants from each soil type, that there is little difference in favor of either method of field sampling. It may be concluded, therefore, that the data collected during the main portion of the investigation represent the average composition of the alfalfa on the plats studied as accurately as though a large number of samples had been taken according to a systematic pattern. The data from the systematic samples do show a considerable variation in composition of alfalfa from different portions of each plat.

TABLE 13.—*Comparisons of results from samples taken by the systematic and random methods of sampling, averaging 2 samples in case of the random method and 12 samples in the systematic method.*

Treatment	Sampling method	Moisture %	N %	CaO %	P_2O_5 %
	Mancelona Gravelly Sandy Loam				
None	Random	10.64	3.20	4.98	0.37
None	Systematic	11.63	3.13	4.75	0.36
600 lbs. 0-0-15	Random	11.76	2.89	2.55	0.40
600 lbs. 0-0-15	Systematic	10.30	2.87	2.54	0.37
	Brookston Clay Loam				
None	Random	10.29	2.98	3.35	0.49
None	Systematic	9.71	2.98	3.06	0.52
300 lbs. 0-20-0	Random	8.97	3.22	2.53	0.63
300 lbs. 0-20-0	Systematic	9.53	3.23	2.47	0.66
	Isabella Sandy Loam				
300 lbs. 0-16-0	Random	10.06	2.93	1.87	0.67
300 lbs. 0-16-0	Systematic	11.20	3.16	2.01	0.71
300 lbs. 4-16-4	Random	10.61	3.07	2.34	0.62
300 lbs. 4-16-4	Systematic	11.79	3.19	2.28	0.67
	Fox Sandy Loam				
Field 1, 250 lbs. 0-20-20	Random	11.72	3.14	1.88	0.57
Field 1, 250 lbs. 0-20-20	Systematic	11.00	3.30	2.00	0.65
Field 2, 250 lbs. 0-20-20	Random	10.21	3.51	1.91	0.71
Field 2, 250 lbs. 0-20-20	Systematic	10.56	3.59	2.09	0.75

GREENHOUSE EXPERIMENTS

The failure of alfalfa grown in the field on fertilized plats to show a consistent response in composition to the fertilizer treatment raised a question as to how definite a correlation between plant composition and fertilizer application alfalfa would show when grown under controlled conditions in the greenhouse.

The Montcalm sandy loam soil was selected for the greenhouse trials. This soil type is fairly widely distributed in the central part of the lower peninsula of Michigan. The soil is undulating to moderately rolling with good drainage, the supply of organic matter is moderate, and the soil is fairly productive and responds well to fertilizer treatment. An acidity requiring about 2 tons of limestone per acre is usually found.

The soil used in the experiments was screened to remove coarse material, thoroughly mixed, and 12-kilogram portions placed in 2-gallon glazed jars. Fertilizer applications as indicated in Table 14 were thoroughly mixed through the dry soil. During the experiment a moisture content of approximately 20% was maintained. All treatments were in duplicate, except 4, 5, 11, 12, 18, and 19, which were in sets of four. Plants were thinned to 10 per pot and good growth was obtained. All cuttings were made in the one-half bloom stage of growth for partial analysis. The first and second cuttings were combined into one sample for analysis as were the third and fourth cuttings.

TABLE 14.—*Effect of 2 tons of limestone plus increasing amounts of 20% superphosphate applied to Montcalm sandy loam soil on the phosphorus and nitrogen content of alfalfa grown in the greenhouse in 1932.*

Pot No.	Superphosphate, lbs.	1st and 2nd cutting			3rd and 4th cutting		
		Water %	N %	P_2O_5 %	Water %	N %	P_2O_5 %
	Series I. High Calcium Limestone Plus 100 lbs. Muriate of Potash						
1	None	11.25	4.25	0.98	7.59	3.55	1.06
2	200	12.81	4.23	1.00	7.51	3.31	1.04
3	400	14.75	4.24	1.05	7.21	3.34	1.03
4	800	9.39	4.26	0.94	7.23	3.51	0.99
5	1,200	9.82	4.19	0.98	7.59	3.51	1.03
6	2,400	10.18	4.22	0.97	8.11	3.48	1.15
7	4,800	10.52	4.22	1.13	8.56	3.51	1.35
	Average	11.25	4.23	1.01	7.69	3.46	1.09
	Series II. High Calcium Limestone						
8	None	8.45	4.31	0.99	8.54	3.55	1.13
9	200	9.43	4.26	0.96	8.58	3.45	1.13
10	400	9.97	4.28	0.98	8.17	3.35	1.07
11	800	7.29	4.26	0.93	9.95	3.64	1.11
12	1,200	8.24	4.27	0.99	9.85	3.65	1.20
13	2,400	7.33	4.16	1.01	8.94	3.65	1.28
14	4,800	7.89	4.17	1.05	8.76	3.50	1.55
	Average	8.37	4.24	0.99	8.97	3.54	1.21
	Series III. High Magnesium Limestone						
15	None	9.29	4.27	0.99	9.64	3.58	1.20
16	200	9.66	4.41	0.96	9.35	3.52	1.10
17	400	10.08	4.29	0.97	9.39	3.56	1.23
18	800	7.49	4.23	0.97	8.89	3.49	1.15
19	1,200	7.72	4.33	0.93	9.09	3.56	1.08
20	2,400	8.07	4.34	1.03	9.13	3.63	1.27
21	4,800	8.24	4.19	1.20	8.94	3.63	1.74
	Average	8.58	4.29	1.01	9.20	3.57	1.25

Table 14 shows that the nitrogen contents of the second samples were decidedly and uniformly lower than those of the first. Soil treatment appeared to make no marked difference in nitrogen content of samples.

The phosphorus contents of the second samples were slightly but uniformly higher than those of the first samples. Heavy applications of superphosphate, 2,400 pounds and especially 4,800 pounds, increased the phosphorus content of the alfalfa in most cases. The results afford some basis for the suggestion that a considerable quantity of superphosphate must be added to this soil before an appreciable increase in the phosphorus content of the alfalfa can be expected. The large quantity of superphosphate required may explain why definite increases in phosphorus content of alfalfa, as a result of phosphorus fertilization, were not obtained in the field experiments reported early in this paper. On the average, application of limestone increased the phosphorus content of the plants in the third and fourth cuttings, but not in the first and second cuttings. The presence of magnesium in the limestone did not increase its effectiveness in this respect. These results are not in accord with those of Kellog (6), who found that magnesium oxide enhanced phosphate availability in soils. Truog (18) attributes this effect to a better calcium-magnesium soil balance in which event the plants are not forced to excess feeding on calcium in order to obtain phosphorus.

SUMMARY

1 This paper reports experimental data obtained from a partial chemical analysis of alfalfa grown on Isabella sandy loam, Montcalm sandy loam, Mancelona gravelly sandy loam, Fox sandy loam, Brookston loam, Brookston clay loam, Brookston silt loam, Gilford loam, and Miami silt loam.

2. The first cuttings of alfalfa grown on the several soil types exhibited a much lower ratio of leaves to stems than the second cuttings at the one-half bloom stage. Also, the weight of stems exceeded that of the leaves in the first cuttings, which was just the opposite of the condition for the second cutting.

3. In both the stems and leaves the nitrogen content tended to be higher in the second than in the first cuttings of alfalfa harvested in the one-half bloom stage.

4. Regardless of soil type and soil treatment the calcium content of alfalfa leaves was from two to three times greater than that of the stems.

5. In case of plants grown on Isabella sandy loam soil the calcium content of the stems tended to be higher in the second than in the first cuttings, but the opposite was true in the case of the leaves. In the other soil types, the data are not complete enough for such comparison.

6. Plants grown on the Isabella sandy loam show that all soil treatments containing limestone increased the nitrogen content of both the stems and leaves but tended to depress the phosphorus content.

7. In general, the plants grown on soils not requiring applications of limestone showed increases in the phosphorus content of both the stems and leaves with fertilizer treatments containing superphosphate alone or with potash.

8. Plants from the Gilford loam were markedly higher in calcium content than plants grown on the other soil types studied.

9. Alfalfa grown on Isabella sandy loam soil showed a decidedly higher phosphorus content in both the stems and leaves than that of plants from the other soil types.

10. Plants grown on Montcalm sandy loam soil in the greenhouse required very heavy applications of phosphate in order to increase their phosphorus content materially.

11. The phosphorus content of alfalfa grown on the soil types studied was not low compared to that of alfalfa from other states.

12. The data presented in this paper indicate no advantage of the systematic over the random method of taking samples of alfalfa for chemical analysis.

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ONE ASPECT OF THE INTERRELATION OF SOIL BACTERIA AND PLANT GROWTH[1]

NORMAN ASHWELL CLARK[2]

THE influence of micro-organisms on the soil has been known since 1875, when bacteria were shown to attack soil organic material and form nitrates. In recent years it has been suggested that micro-organisms may affect the green plant by producing unknown substances in soil organic matter which are either essential for growth or which influence markedly the composition of the plant.

Very small amounts of organic matter have a noticeable effect on the growth of plants in water cultures. Bottomley (1)[3] and Mockeridge (8) at the University of London, in their experiments with the plant Lemna, could not obtain growth and reproduction in inorganic salt solutions without adding extracts from soil or manure. They came to the conclusion that organic matter of a special kind, present in soils, peats, and farmyard manure, was *essential* for good growth of green plants, and that these unknown compounds were the result of bacterial action. They believed that these compounds were similar to vitamins in animal life and that they were just as essential for plant life.

That organic matter was not necessary for the growth and reproduction of Lemna was shown by Clark and Roller (4), and confirmed by others, but the possibility remained that the composition of the plant was affected. The known value of farmyard manure in the production of crops and the experiments on plant growth of Schreiner and Skinner (10) and others in the Bureau of Soils, of Wolfe (14), and of Clark and Roller (5) with Lemna under sterile conditions indicated that, while many organic compounds would not stimulate plant growth, some special organic substances, particularly in the presence of micro-organisms, could affect the plant. This view is also held by a number of workers in southern India, among them McCarrison (7) and Viswa Nath (13).

Viswa Nath (12) believes micro-organisms in the soil act on organic matter and liberate some active constituent which is absorbed by the plant. This is either passed to the seed or causes some special metabolism in the plant, producing substances which are not formed without the active constituent. This belief is based upon a large number of experiments on grains in India, particularly at the Agricultural Research Institute at Coimbatore One of the interesting observations made is that seeds from plats under various fertilizer treatments give large variations in the following crops under the same treatments Millet obtained from plats receiving farmyard manure produced better crops than millet from plats receiving commercial fertilizers

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[3]Figures in parenthesis refer to "Literature Cited," p. 103.

when both lots of seed were sown under the same conditions the following season.

McCarrison (7) carried out animal nutrition experiments with the grain obtained from differently fertilized plats, and as before, the grain from the farmyard manure plat proved of greater value than that from plats with mineral fertilizers, but neither size nor composition of the grain showed appreciable differences. McCarrison attributed the difference to the vitamin content, and in experiments on pigeons and rats, both with millet and wheat, found that the vitamin B content was distinctly higher in the grain from plats treated with cattle manure, and also found indications that pointed to the same fact for the vitamin A content.

From these results Viswa Nath (13) argued that, as the grain from the cattle-manured plats was richer in plant growth stimulant and also in vitamins, the plant stimulant and the vitamin might be either the same, or else interrelated so that the stimulant would enable the plant to form the vitamins. He found that the more decomposed the manure, the greater the amount of plant stimulant in the seed. Yeast, known to produce vitamins, also stimulated plant growth. The suggestion was that micro-organisms are concerned in the process of stimulant production, the final conclusion being that the chain reaches from the bacteria at the start, through the organic matter, the plant-stimulating substances, the vitamins produced in the plant, to the utilization of these in animal life The importance to south India, where millet is the main staple in the diet of thousands, is obvious The theory is similar to that of Bottomley and Mockeridge of 15 years ago, without the emphasis on the presence of organic matter as essential to the life of the green plant.

There are two investigations which bear upon this theory. In 1927, Hunt (6) reported on the vitamin B content of wheat which had been grown on plats under varying fertilizer treatment for some 35 years He found little or no influence due to the varying treatments, although from year to year the B content varied widely, indicating a climatic effect. In 1932, Virtanen and van Hausen (11) of Finnland grew peas under sterile and non-sterile conditions. They determined carotin in the plants, but found no marked difference in quantity. Vitamin C was also checked by a chemical method with similar results. It may be noted that the peas here were only one generation away from the soil and presumably might have contained the stimulant in sufficient quantities to produce the vitamins.

At Iowa State College we had grown Lemna for several years through hundreds of generations in the absence of micro-organisms and in inorganic salt solution, as well as non-sterile plants on a soil-water mixture. The Lemna can produce flowers, but usually propagates asexually by putting out a small frond or leaf which grows to the size of the parent and then separates. Here was an opportunity to test the presence or absence of vitamins in plants which were completely out of the influence of micro-organisms.

The writer interested Dr. B. H. Thomas in the problem. Dr. Thomas, who was working with vitamin A on a large colony of rats agreed to test the Lemma with the rats. Seventeen rats of about the

same size and development were selected and were placed on a diet devoid of vitamin A but containing everything else necessary. At the time the experiments started these rats had ceased to increase in weight for several days and had developed marked xerophthalmia.

The rats were divided into four groups. The controls were fed the basal A-free ration. Of these, three died before the end of the experiment and the fourth a few days later. The second and third groups were used for a comparison of the vitamin A in plants grown in a non-sterile mixture of soil-water and in those reproducing free of micro-organisms in a purified salt solution. These plants were collected each week, air dried in the dark, and after being finely ground, were included in the basal ration to the extent of 0.5% dry weight. The fourth group of rats was fed daily, by hand, 0.25 gram each of the fresh green plants from the soil, this amount providing approximately the same weight of dry matter from the Lemna as that consumed by those taking the dry plants.

The results were never in doubt. All three groups receiving the Lemna showed the results of the vitamin A almost at once. The xerophthalmia cleared up and the rats started to gain weight. The weight curves for those on the dry sterile plants parallelled very closely the curves for those on the non-sterile plants. The average gain for the 24 days was 29 grams for each rat. The rats on the fresh plants put on weight somewhat faster, suggesting that part of the vitamin had been destroyed by the drying process. This loss on drying has been observed before with other green plants.

The uniform rate of growth made by the two groups which received sterile and non-sterile plants is an indication that not only is the vitamin formed in plants which have been removed from the influences of micro-organisms for hundreds of generations, but also that there is little difference in the quantity produced. A secondary item of interest is that while the non-sterile Lemna were grown principally in sunshine, the sterile plants were produced under electric light (3).

In these experiments the absence of the micro-organisms and the variation in light have had little influence on the formation of vitamin A in the Lemna. But vitamin A is probably not produced to any extent by bacteria, and for other vitamins there might be quite different results. It was for vitamin B that McCarrison's results were most evident, and that particular vitamin is produced by bacteria. The writer cannot yet report successful experiments with vitamin B.

An attempt was made to check vitamin B, not distinguishing between B and G, by feeding the fruit fly, *Drosophila melanogaster*, as it has been reported that vitamin B is essential for these flies. The larvae feed on yeast, which of course contains vitamin B, but it was not possible to get them to grow when freed from micro-organisms on a synthetic medium, with the vitamin B of the extracted yeast added to the medium. We thought to substitute the Lemna extract for the yeast extract. This would have needed a far smaller quantity of the Lemna plants than rat feeding, and the production of the sterile plants is time consuming.

At the present time, therefore, we have an open mind on the question. We believe that green plants will grow, remain healthy, and

reproduce without any organic matter or bacteria. We believe that certain types of organic substances, expecially in the presence of bacteria, may markedly effect the plant constitution, but whether this is due to the formation of an auximone, or its connection with vitamins, we do not know.

Olsen (9), at the Carlsberg Laboratories in Denmark, believes that the whole effect is in the iron supply. The iron in the organic combination is more available to plants, whereas in most combinations when the pH of a solution is higher than 5, iron tends to precipitate as ferric hydroxide and becomes unavailable to the plant. Burke, *et al.* (2) has pointed out that the Fe humate combination, whether a true chemical combination or colloidal, holds the iron in solution at higher pH values, thus keeping it available for plants. Burke also showed that the growth of Azotobacter responded quantitatively to the Fe content when organic matter was added. It does not look, however, as if the iron would be responsible for the change in feeding value of grains as given by McCarrison; and Viswa Nath certainly does not agree with this explanation.

The problem of the effect of organic matter on the plant and the part played by bacteria is still unsettled.

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THE RHYTHMICAL NATURE OF MICROBIOLOGICAL ACTIVITY IN SOIL AS INDICATED BY THE EVOLUTION OF CARBON DIOXIDE[1]

F. B. SMITH, P. E. BROWN, AND H. C. MILLAR[2]

THE factors influencing the production of carbon dioxide in soils have been the subject of many investigations. The evolution of carbon dioxide from soils has long been regarded as a measure of microbiological action, although it is now recognized that this may be a rather liberal interpretation of the facts. However, numerous experiments have shown a fair degree of correlation between the amounts of carbon dioxide produced in soils and the numbers of micro-organisms present. Experiments have also shown a relationship between the evolution of carbon dioxide from soils and the activity of certain physiological groups of soil micro-organisms.

It is common knowledge that microbiological activity in soils may be increased at first and then decreased when field soils are brought into the laboratory. This stimulation is evidenced by an increase in numbers of organisms and also by an increase in the amount of carbon dioxide produced.

Johansson (3)[3] observed a regular periodic fluctuation in the production of carbon dioxide in forest soils when the soils were incubated in the laboratory under control conditions. He also found that the amount of carbon dioxide produced during the day was often greater than the amount produced during the night.

The purpose of this investigation was to determine the rate of evolution of carbon dioxide from soils variously treated and to study the relationship of carbon dioxide production to microbiological activity in soils. The data reported in this paper are the results of preliminary work done on the first part of the problem.

METHODS OF PROCEDURE

The amount of carbon dioxide evolved from the soil was determined at 12-hour intervals for periods of 5 to 15 days. Duplicate samples of the moist soil which had been passed through the 2-mm sieve and thoroughly mixed were weighed out and placed in 400-cc beakers. Samples of the moist soil equivalent to 400 grams of the dry soil were used and the moisture content adjusted to 25% by the addition of distilled water. The beakers containing the soil were then placed in respiration chambers and incubated at 27° to 28°C.

The respiration chambers used in these experiments were made from 1-gallon tin buckets and are similar in principle to the apparatus described by Lundegardh (4), Fehér (2), and Johansson (3). A wire loop was soldered inside the bucket to support the beaker containing the sample of soil. A hole was cut in the

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[2]Associate Professor, Professor, and Fellow, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 108.

opposite side of the bucket and a ¼-inch collar soldered on the outside. A No. 7, two-hole rubber stopper fitted with a tube for introducing the barium hydroxide and with a guard tube of soda-lime was placed in this opening. Another opening was made in the bottom of the bucket and fitted with a tube closed by a pinch cock. The barium hydroxide was drained from the bucket for titration without disturbing the sample. Three pieces of No. 9 galvanized iron wire 8 inches long soldered on served as legs to support the buckets (Fig. 1).

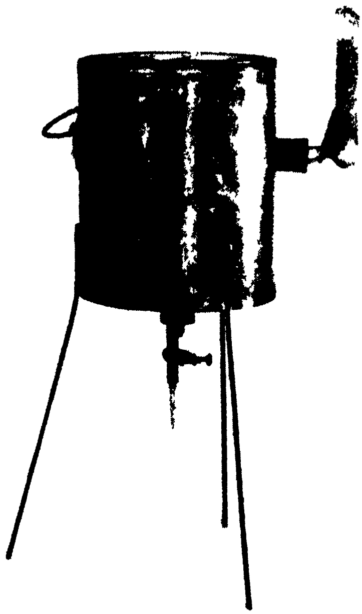

FIG. 1.—Respiration chamber.

The inside of the buckets was covered with paraffin. The samples were placed in the buckets and the lids sealed air-tight with paraffin. Fifty cc of 0.1 N barium hydroxide were added through the tube provided for this purpose. The amount of carbon dioxide was determined by titrating the barium carbonate and excess barium hydroxide against 0.1 N hydrochloric acid, using phenolphthalein as the indicator.

Two series of experiments were conducted from which samples of soil were taken for the laboratory tests. In the one series, field soils which had been treated previously were sampled and the evolution of carbon dioxide determined in the laboratory at 12-hour intervals for 5 to 15 days. In the other series, soils treated in the greenhouse in 4-gallon pots were sampled at regular intervals and the evolution of carbon dioxide determined in the laboratory at 12-hour intervals for 10 to 11 days.

RESULTS

SERIES I

Seven plats of Carrington loam 14 by 56 feet with 7-foot borders were treated May 20. The soils were kept fallow and samples for carbon dioxide production determinations taken June 20 and August 20. The average rates of carbon dioxide production for all treatments in the two experiments are shown in Fig. 2.

The data showed a small but significant difference in the rate of carbon dioxide evolution in the soils from the different plats one month after treatment, but these differences had disappeared three months after treatment. However, the rate of production of carbon dioxide at the 12-hour periods fluctuated similarly in all soils and the average rates of production only are shown for the two experiments.

An analysis of variance of the data showed a highly significant difference in the average rate of production of carbon dioxide between the 12-hour periods. In both experiments the average rate of pro-

duction of carbon dioxide decreased rapidly during the first 36 hours, then the rate of production fluctuated more or less regularly at 12-hour intervals between high and low values. The difference between the maximum and minimum values gradually became smaller as the experiment continued until the 12th day in the second experiment when a high maximum rate of production was attained. The rate of production of carbon dioxide after the first 36 hours was usually

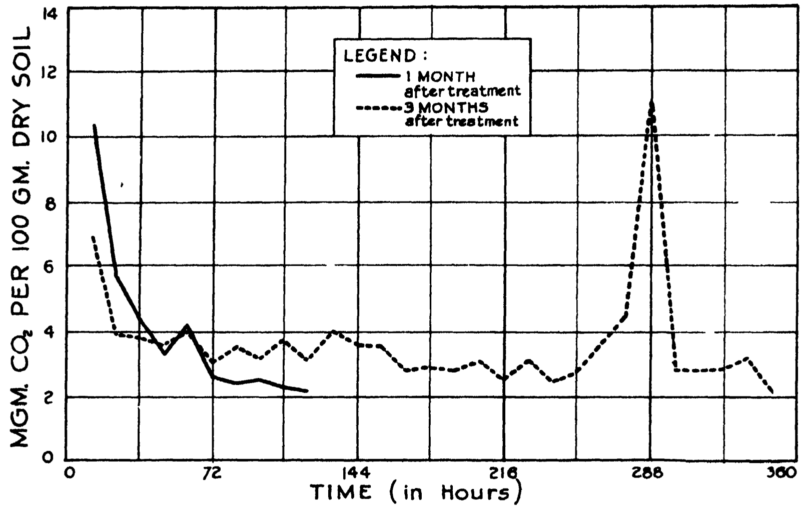

FIG. 2. –Average rate of carbon dioxide production in field soils sampled one month and three months after treatment.

higher during the day than during the night. However, the highest rate of production in the second experiment was obtained during the night period.

SERIES II

The soil used in this series of experiments was a Carrington loam having a pH of 6.33. The soil was taken from the College agronomy farm in a permanent pasture. In securing the soil the grass sod was removed and the soil below was taken to a depth of 6 inches. It was brought into the greenhouse, passed through a quarter-inch screen, and thoroughly mixed. Thirty-nine pounds of soil were placed in each of 32 4-gallon pots.

Two series of 16 pots each were set up and 4 pots of soil in each series were treated according to the following outline, the materials being thoroughly mixed with the soil:

A, Check
B, 0.2% oat straw
C, 0.2% oat straw and 0.2% rock phosphate
D, 0.2% oat straw, 0.2% rock phosphate, and 0.1% limestone

The oat straw used was ground to pass the 0.5-mm sieve and contained 0.61% nitrogen. The rock phosphate was approximately 100-mesh and contained 31.82% P_2O_5. The limestone was about 40-mesh and contained 80% calcium carbonate.

The soils in four pots of each of these treatments received no further treatment (Series 1) and served as checks. Carbon dioxide-saturated water, referred to as carbonic acid and having a pH of 4.2, was added to the soils of four pots of each treatment (Series 2). The moisture content of the soil was adjusted to 20% and maintained at that amount throughout the experiment by the addition of distilled water except in the case of Series 2 where carbonic acid was used. The soils

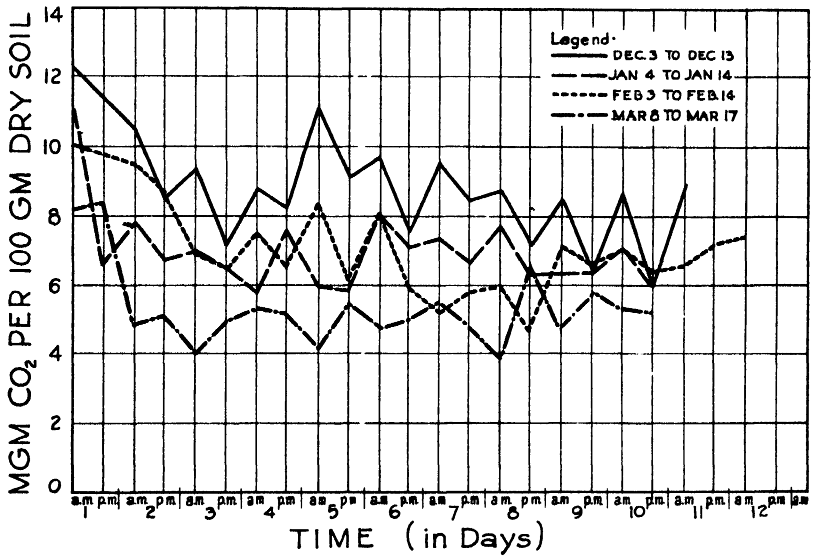

FIG. 3.—Average rate of carbon dioxide production in greenhouse soils.

of one pot of each treatment were kept fallow and samples taken at intervals for the determination of the production of carbon dioxide in the laboratory. The two series of experiments and the four treatments in each series are illustrated in the following outline:

No.	Series 1 (check)	Series 2 (carbonic acid treated)
1	Untreated	Untreated
2	Straw	Straw
3	Straw + phosphorus	Straw + phosphorus
4	Straw + phosphorus + lime	Straw + phosphorus + lime

The soils were treated in the greenhouse November 1 and samples taken for determining the rate of carbon dioxide evolution December 3, January 4, February 3, and March 8. The average rates of carbon dioxide production at the different samplings are shown in Fig. 3

The data showed a highly significant difference between the rate of production of carbon dioxide in the differently treated soils, but the fluctuations in the rate of production at the 12-hour periods were similar and only the average rate of production in each experiment is given.

DISCUSSION OF RESULTS

The data obtained in the foregoing experiments show that the rate of carbon dioxide production in soils decreased rapidly during the first one to three days of incubation in the laboratory. The initial period of decreasing rate of production was usually followed by a period of regular fluctuations between high and low rates of production and then the cycle was repeated. A statistical analysis of the data showed that these fluctuations were not merely chance variations, but that there was a highly significant tendency toward a rhythmical periodicity in production of carbon dioxide in the soils.

Bal (1) has investigated the decreasing rate of production of carbon dioxide in soils incubated in the laboratory and found that it was not caused by a lack of available carbon nor by soluble toxic substances produced by the organisms themselves.

Johansson (3) stated that the periodicity in the rate of carbon dioxide production could be explained if one assumes a variation in the rate of metabolism of the soil micro-organisms or fluctuations in the growth velocity. The latter assumption, it was pointed out, is supported by evidence that the rate of cell division of some of the higher plants is greater during the day than during the night.

The data obtained in these experiments show that there was no correlation between the amount of carbon dioxide produced during the day or at night and the periods of high rate of production. That there were rather definite cycles between the periods of high and low rates of production, there can be no doubt but the 12-hour intervals were too long to define these periods accurately.

There is no experimental evidence for the assumption that there are periodic variations in the rate of respiration of the organisms. However, the amount of carbon dioxide produced during the various phases of growth in a bacterial culture might vary. That is, during the logarithmic growth phase, more carbon might be required for the metabolism of cells and a smaller proportion used for energy but with an increasing number of cells respiring. During the logarithmic death phase a larger proportion of carbon might be used for energy purposes than for cell metabolism, but there are also a decreasing number of cells to respire during this phase. Even if this were the explanation of the phenomena, it would be difficult to conceive of a mixed culture of soil micro-organisms having generation time and metabolic processes sufficiently similar to produce regular periodic fluctuations in the rate of carbon dioxide production. The problem is being studied further with the hope of defining more clearly the relationship between carbon dioxide production and microbiological action in soils.

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THE DECOMPOSITION OF LIGNIN AND OTHER ORGANIC CONSTITUENTS BY CERTAIN SOIL FUNGI[1]

F. B. SMITH AND P. E. BROWN[2]

THE significance of organic matter in the soil is apparent from the definition of soil, for without it there is no soil. The organic matter of the soil is derived from plant and animal remains, and it exists in all stages of decomposition. De'Sigmond (1)[3] has grouped these stages into four classes, namely, (a) the raw undecomposed dead organic matter, (b) the solid decomposed material, (c) the material soluble or dispersed in the soil solution, and (d) the more or less volatile end products, such as carbon dioxide, ammonia, and hydrogen. It is apparent from this classification of organic matter that in time it will all disappear completely from the soil unless additions are made more or less regularly.

Numerous investigations have been conducted to study the influence of age of the plant, the chemical composition of the plant, and the kind of organic matter upon the rate of decomposition of plant materials. The factors influencing the growth of micro-organisms, such as reaction, temperature, moisture, and oxygen requirements, have probably received more attention than any other phases of the subject. Recently, the results of considerable study on fermentations have been reported, but much of this work has involved merely a determination of the products formed by specific organisms upon a given substrate. It would seem desirable to study the rate of decomposition of the fertilizing materials which supply organic matter on the farm or of some of the principal constituents of this organic matter. The purpose of this work was to determine the rate of decomposition of several forms of organic matter when acted upon by certain common soil fungi. This paper is a progress report on the project.

METHODS OF PROCEDURE

Experiments were conducted to determine the rate of decomposition of lignin, xylan, cellulose, and oat straw. Pure cultures of *Trichoderma lignorum*, *Aspergillus terreus*, *A. niger*, *Penicillium vinaceum*, *Stereum purpureum*, and a soil infusion were used for the inoculation. In these experiments soil, sand, or a mineral salt solution were employed as the medium. The rate of decomposition was measured by the evolution of carbon dioxide.

The xylan and lignin were prepared by the method of Peterson and Hixon (2). The analysis of the xylan showed the following:

Moisture (loss at 100°C)	14.79%
Ash	17.33%
Carbon	28.46%
Pentosan (by furfural)	64.15%

[1]Contribution from the Department of Farm Crops and Soils, Iowa State College, Ames, Iowa. Published as Journal Paper No. J-152 of the Iowa Agricultural Experiment Station. Project No. 225. Also presented at the annual meeting of the Society held in Washington, D. C., November 23, 1934. Received for publication November 23, 1934.

[2]Associate Professor and Professor, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 119.

The analysis of the lignin showed:

Moisture (loss at 100°C)	7.72%
Ash	1.09%
Carbon	44.53%
Lignin (72% H_2SO_4)	88.66%

The cellulose used was prepared by extracting the residue after the NaOH extraction twice with dilute HNO_3. The residue was then washed free of HNO_3 and treated with $NaHSO_3$. The material was suspended in water and SO_2 bubbled through it, after which it was washed and dried. The analysis of this material showed:

Moisture (loss at 100°C)	4.78%
Ash	7.42%
Carbon	26.34%
Cellulose	78.97%

RESULTS

DECOMPOSITION OF XYLAN, LIGNIN, AND CELLULOSE IN CARRINGTON LOAM BY *Aspergillus terreus*, *Trichoderma lignorum*, AND *Penicillium vinaceum*

One hundred gram equivalents of dry Carrington loam which had been passed through the 2-mm sieve were weighed out on a paper and the material used as a source of carbon mixed thoroughly with the soil, then placed in a calibrated, 1-liter Erlenmeyer flask. The lignin, xylan, and cellulose were added to the soils in amounts equivalent to 300 mgm of carbon. The moisture content of the soil was adjusted to 25% and the flasks plugged with cotton, and sterilized at 15 pounds pressure for 1 hour on each of three consecutive days. Plates poured from soils sterilized in this manner never showed growth and the soils were considered to be sterile.

The organisms used to inoculate the soils were grown on agar slants for one week, after which 10 cc of sterile tap water were added, the tube shaken, and a 1-cc suspension taken for inoculation. After inoculation the flasks were fitted with a sterile 2-hole rubber stopper which carried an inlet tube, an outlet tube, and a mercury-seal stirrer. The flasks were then placed in the water bath at a temperature of 30°C and carbon dioxide determined volumetrically at intervals. The results obtained are shown in Figs. 1 and 2.

Aspergillus terreus.—Xylan was decomposed more rapidly at first than cellulose by *A. terreus*, but after 140 hours the cellulose was decomposing more rapidly than the xylan (Fig. 1). Approximately 500 mgm of carbon dioxide were evolved from the soil treated with cellulose and 320 mgm from the soil treated with xylan. The carbon dioxide equivalent of carbon added in each case was 1,100 mgm. The soil treated with lignin evolved a slightly greater amount of carbon dioxide than the untreated soil.

Trichoderma lignorum.—Cellulose was decomposed more rapidly than xylan at first by this organism, but the trend was reversed after about 200 hours (Fig. 2). Slightly more carbon dioxide was produced in the untreated soil than in the soil treated with lignin.

Penicillium vinaceum.—Growth was poor at first in all soils inoculated with this organism (Fig. 2). After 500 hours the soil treated with xylan had evolved a total of 233 mgm of carbon dioxide. Carbon dioxide production by the organism in the soil treated with lignin was slightly less than that of the check soil and only slightly greater in the soil treated with cellulose.

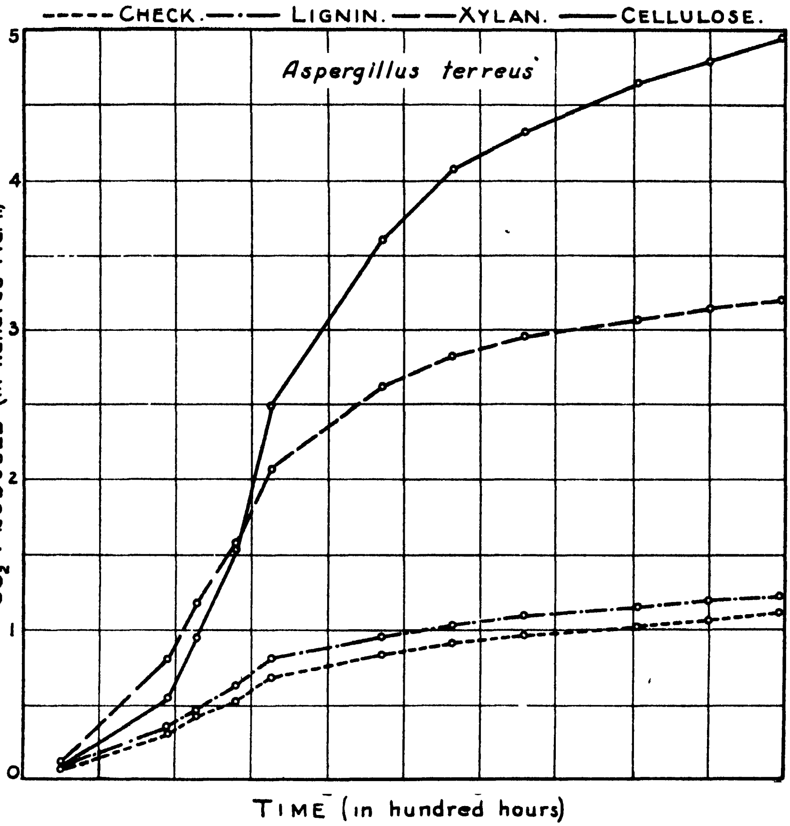

FIG. 1 Decomposition of lignin, cellulose, and xylan by *A. terreus* in the soil

DECOMPOSITION OF XYLAN, CELLULOSE, AND LIGNIN IN A SOLUTION CULTURE MEDIUM BY *Trichoderma lignorum*, *Aspergillus terreus*, AND *Penicillium vinaceum*

In this series of experiments the materials were added to 100 cc of a culture solution consisting of the following:

Peptone	0.5%
KH_2PO_4	0.1%
$MgSO_4$	0.05%
Distilled water	1 liter

One hundred cc of this solution were placed in 500-cc extraction flasks and sterilized 15 minutes at 15 pounds pressure. After sterilization the flasks were inoculated and placed in the culture room at a

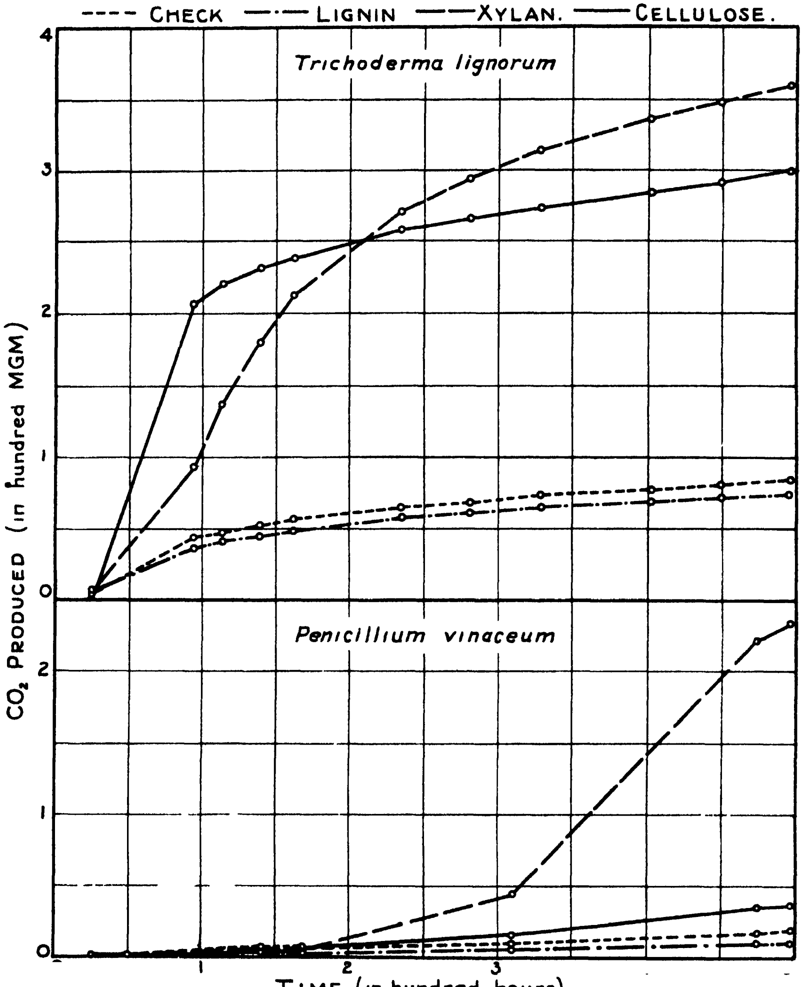

FIG. 2.—Decomposition of lignin, cellulose, and xylan by *T. lignorum* and *P. vinaceum* in the soil.

temperature of 28°C. Carbon dioxide-free air was drawn through the cultures and the carbon dioxide evolved absorbed in approximately 0.5 N KOH. The carbon dioxide was determined by titrating the excess KOH with standard HCl after the addition of $BaCl_2$. The results obtained are presented in Figs. 3 and 4.

Aspergillus terreus.—The initial rate of carbon dioxide evolution was largest where lignin or cellulose was used, but after 96 hours

carbon dioxide evolution was less rapid with these materials than in the peptone medium alone (Fig. 3). During the interval from 48 to 96 hours, carbon dioxide was being evolved more rapidly from the xylan than from the check, but after 400 hours only 69 mgm more carbon as carbon dioxide had been evolved.

In an inorganic salts solution with KNO_3 as a source of nitrogen instead of peptone, *A. terreus* decomposed xylan rapidly during the

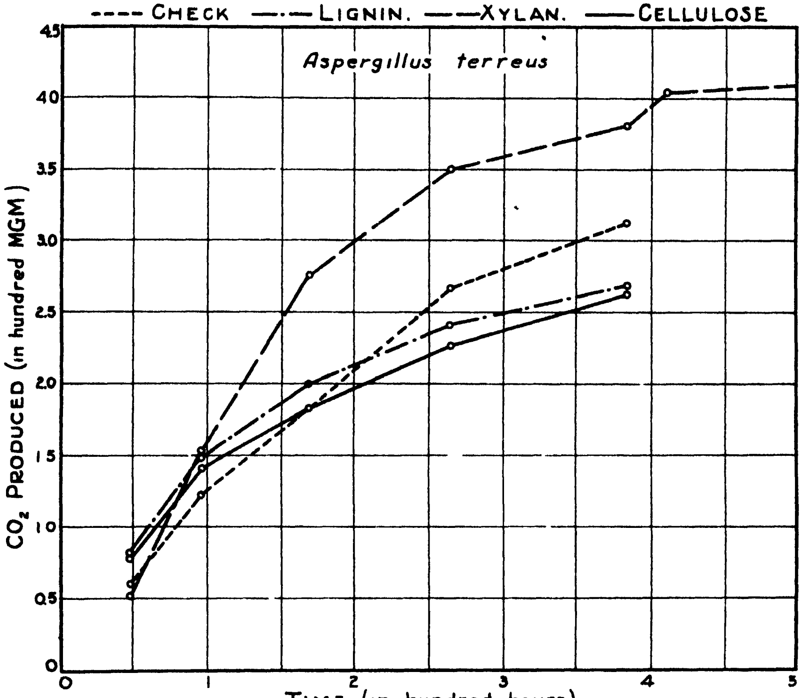

FIG 3.—Decomposition of lignin, cellulose, and xylan by *A terreus* in a peptone medium.

first 300 hours, after which the rates of decomposition of xylan and cellulose were approximately the same (Fig. 5). Of the 100 mgm of carbon added as xylan, 55 mgm were evolved as carbon dioxide after 450 hours. Some decomposition of cellulose and lignin occurred during this time, 21 and 20 mgm, respectively, of the 100 mgm of carbon added being evolved as carbon dioxide

Trichoderma lignorum.—There was a slight stimulation in the initial rate of carbon dioxide evolution with all the materials inoculated with *T. lignorum* over that in the check (Fig. 4). With lignin and cellulose there was slightly less carbon dioxide finally than in the check, whereas when xylan was used there was slightly more carbon dioxide than in the check.

Penicillium vinaceum.—Xylan, lignin, and cellulose stimulated carbon dioxide production by *P. vinaceum* during the period from 48

to 168 hours, but all the treated cultures yielded less carbon dioxide than the check after about 400 hours of incubation (Fig. 4).

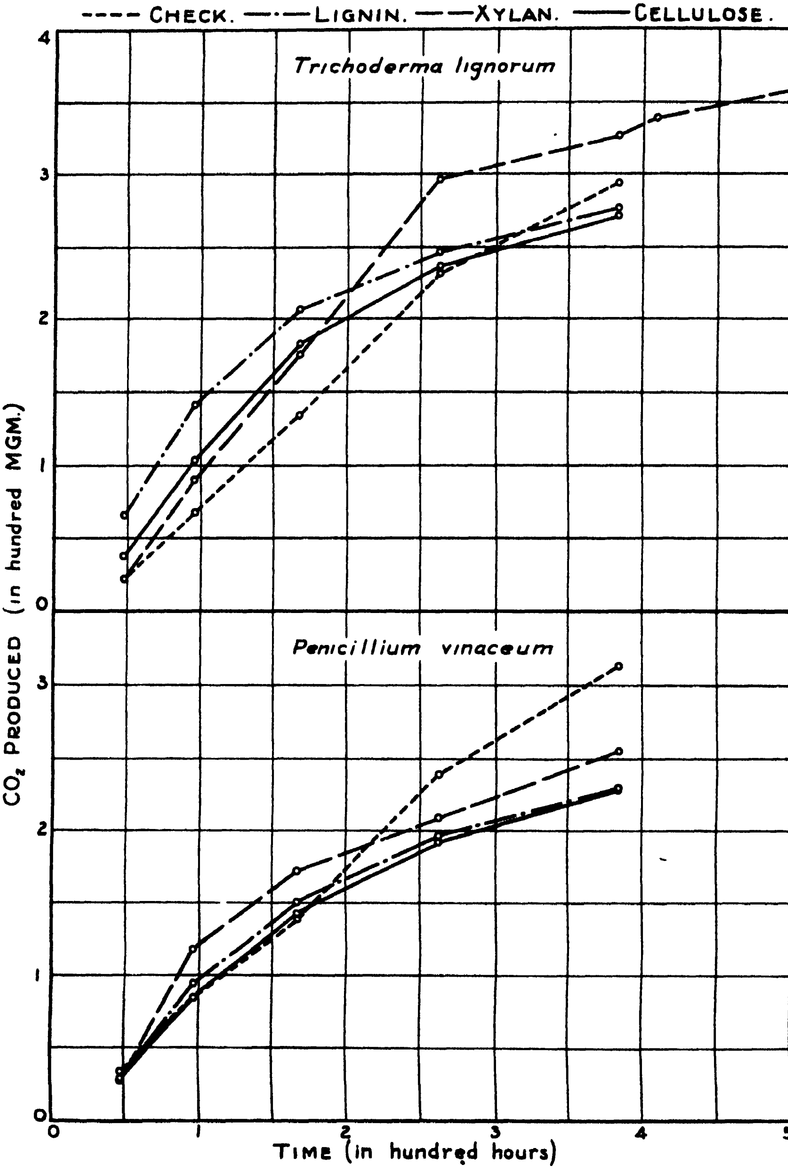

FIG. 4.—Decomposition of lignin, cellulose, and xylan by *T. lignorum* and *P. vinaceum* in a peptone medium.

DECOMPOSITION OF XYLAN, LIGNIN, CELLULOSE, AND OAT STRAW IN SAND BY *Aspergillus niger* AND A MIXED CULTURE OF SOIL MICRO-ORGANISMS

Three hundred grams of pure quartz sand were thoroughly mixed with 0.3 gram of carbon as xylan, cellulose, or lignin in a Fernback flask. Quadruplicate flasks were treated with each of the materials and four flasks were left untreated. The moisture content was adjusted at 5% and the flasks sterilized at 15 pounds pressure for 30 minutes on each of three successive days. After sterilization they were inoculated with a 10-cc suspension of the organisms and the moisture content adjusted to 25% by the addition of a sterile nutrient solution which contained 0.24% ammonium sulfate, 0.02% monopotassium phosphate, and 0.02% magnesium sulfate. The treatments were as follows:

Flask No.	Organism	Carbon source
1	*A. niger*	None
2	*A. niger*	None
3	*A. niger*	Xylan
4	*A. niger*	Xylan
5	*A. niger*	Cellulose
6	*A. niger*	Cellulose
7	*A. niger*	Lignin
8	*A. niger*	Lignin
9	*A. niger*	Straw
10	*A. niger*	Straw
11	Soil infusion	None
12	Soil infusion	None
13	Soil infusion	Xylan
14	Soil infusion	Xylan
15	Soil infusion	Cellulose
16	Soil infusion	Cellulose
17	Soil infusion	Lignin
18	Soil infusion	Lignin
19	Soil infusion	Straw
20	Soil infusion	Straw

The flasks were placed in the culture room and incubated at 28°C for 13 days and the carbon dioxide evolved determined by aspiration with carbon dioxide-free air and absorption in KOH. The results are presented in Table 1.

The data in the table show that the decomposition of straw follows essentially the decomposition of cellulose and xylan by *A. niger* and the soil infusion. In the case of both cultures the initial decomposition of straw follows that of the decomposition of cellulose, then it follows more nearly the course of the decomposition of xylan. A slight initial decomposition of lignin by *A. niger* and some depressing effect at the end of the experiment were indicated.

TABLE 1.—*Milligrams of carbon dioxide produced by A. niger and a mixed culture of soil micro-organisms in sand from various organic constituents.*

Time in hours	Check		Lignin		Xylan		Cellulose		Straw	
	A*	B*	A	B	A	B	A	B	A	B
30	2.5	6.1	3.6	5.3	4.0	1.9	11.7	23.2	10.0	24.8
59	8.7	13.1	8.8	12.1	9.5	27.0	21.8	50.3	26.1	57.7
96	13.5	16.8	14.7	18.8	27.6	75.6	29.6	72.1	41.3	104.0
144	22.3	25.7	19.9	23.0	104.2	131.8	37.5	98.3	62.6	142.5
192	32.6	30.4	26.7	29.1	193.8	186.4	47.8	125.3	102.4	198.8
246	40.4	35.0	30.1	38.3	261.0	241.9	62.8	159.5	141.9	222.4
312	54.3	44.1	43.7	46.4	337.9	301.9	78.1	190.1	173.7	253.9

*A = *A. niger*; B = Soil infusion.

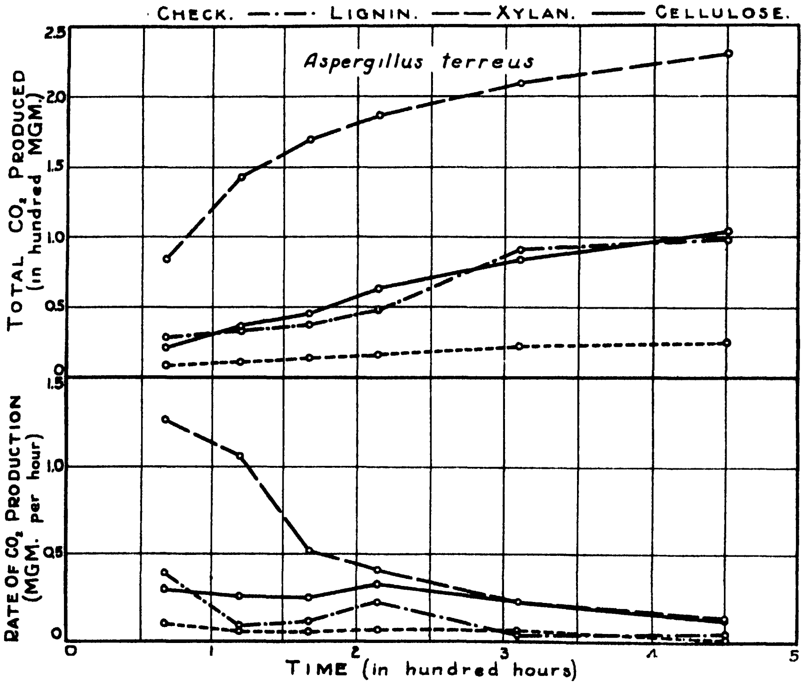

FIG. 5.—Decomposition of lignin, cellulose, and xylan by *A. terreus* in an inorganic salt solution.

DECOMPOSITION OF XYLAN, CELLULOSE, LIGNIN, AND STRAW BY A SOIL INFUSION IN SOLUTION CULTURES

Three hundred milligrams of carbon as xylan, cellulose, lignin, or oat straw were added to 300 cc of a nutrient solution containing the following:

KH_2PO_4	0.02%
$NaNO_3$	0.2 %
$MgSO_4$	0.02%

The solutions were sterilized at 15 pounds pressure for 30 minutes. The treatments made were the same as those shown on page—. The cultures were incubated 15 days and the carbon dioxide evolved was determined as in the previous experiment. The results obtained are presented in Table 2.

TABLE 2 —*Milligrams of carbon dioxide produced by a soil infusion in solution from various organic constituents.*

Time in hours	Check	Lignin	Xylan	Cellulose	Straw
48	15.9	22.2	20.2	44.8	37.8
69	25.1	32.0	42.6	66.5	71.6
111	48.6	39.0	75.3	81.4	92.3
132	37.5	45.7	100.8	——	112.2
156	47.4	54.5	122.7	125.6	145.5
235	56.4	85.2	189.6	——	192.7
285	63.9	98.5	234.1	203.7	230.4
303	68.7	116.7	256.2	231.3	254.5
315	77.4	123.9	282.2	256.5	282.9
367	90.5	131.2	318.9	287.9	322.1

The data in the table show that with the soil infusion there was a considerable evolution of carbon dioxide in all cultures. Cellulose and straw were decomposed more rapidly at first than the other materials. Apparently, some decomposition of the lignin was brought about by the soil infusion. There was an average of 40.7 mgm more carbon dioxide evolved from the flasks containing the prepared lignin than from the checks. However, by analysis 2.53% of the lignin was unaccounted for, and the oxidation of this material might account for some of this carbon dioxide. On the other hand, assuming the lignin unaccounted for by analysis to contain 50% carbon and that it was completely oxidized to carbon dioxide, only 14.6 mgm carbon dioxide can be accounted for, leaving 26.1 mgm carbon dioxide which presumably resulted from the decomposition of the lignin. This represents, however, a small amount, only about 2.3% of the lignin added.

DECOMPOSITION OF LIGNIN BY *Stereum purpureum* IN SAND CULTURES

The results in the preceding experiments indicate that prepared lignin is quite resistant to aerobic decomposition. However, results obtained in studies on the production of artificial farm manure (3) indicated that natural plant lignin decomposed quite completely. It is possible that in the extraction of lignin the lignin is changed into a form more resistant to decomposition than the natural plant lignin or that after extraction it possesses antiseptic or toxic properties. It is also quite possible that some chemical change in the lignin took place during the fermentation of the compost which rendered the lignin available and then biochemical oxidation took place.

To study this problem three lignin products, namely, "Ca-lignin", "oxidized-lignin", and "Iodo-carboxy-lignin"[4] (4), were prepared, and the rate of decomposition determined as in the preceding experiments.

The "Ca-lignin" was prepared according to the following procedure. A quantity of H-lignin extracted from oat straw was dissolved in concentrated ammonium hydroxide and filtered. A quantity of calcium chloride was dissolved in concentrated ammonium hydroxide and filtered. The two solutions were diluted with cold distilled water (10°C) and then mixed. A brownish-yellow precipitate was obtained which was centrifuged and washed by decantation and centrifuging four times with cold distilled water. The precipitate was then resuspended in cold distilled water, aerated until free of amonia, and filtered. The "Ca-lignin" was slightly soluble in water. After the aeration the suspension was filtered, dried at a low temperature (50°C), and ground.

The "oxidized lignin" was prepared by treating 2.0 grams of H-lignin with 20 cc of a 1% solution of hydrogen peroxide at room temperature over night. The material was then dried at a low temperature, 50°C.

Duplicate 100-gram samples of pure quartz sand were weighed into 1-liter Erlenmeyer flasks. The materials used as a source of carbon were added in the amount of 0.2 gram and thoroughly mixed with the sand. Thirty cc of an inorganic salt solution containing 0.2% $NaNO_3$, 0.02% K_2HPO_4, and 0.01% $MgSO_4$ were added and the cultures sterilized for one hour at 15 pounds pressure on each of three consecutive days. The flasks were then inoculated with *Stereum purpureum*, placed in the incubator at 28°C, and the amount of carbon dioxide evolved determined at intervals as in the previous experiments. The treatments made and the results obtained after incubation for 115 days are presented in Table 3.

TABLE 3.—*The decomposition of lignin by Stereum purpureum in sand cultures.*

Flask No.	Carbon source	Average mgm CO_2 produced in 115 days	Average increase over check, mgm
1	None	38.5	——
2	H-lignin	85.6	47.1
3	"Ca-lignin"	73.6	35.1
4	"Oxidized-lignin"	111.1	72.6
5	"Iodo-carboxy-lignin"	72.1	33.6
6	Cellulose	61.8	23.5
7	Cellulose + H-lignin	279.3	240.8
8	Xylan	267.9	229.4
9	Xylan + H-lignin	287.8	249.3

The results show that *Stereum purpureum* is able to utilize lignin, xylan, and cellulose extracted from oat straw. Xylan was readily attacked by this organism, whereas H-lignin and cellulose were utilized more slowly. The addition of H-lignin to the cellulose apparently stimulated the decomposition of the cellulose. The "Ca-

[4]By courtesy of Dr. A. W. Walde, Chemistry Department, Iowa State College.

lignin" and the "Iodo-carboxy-lignin" were less readily decomposed by this organism than the H-lignin. Mild oxidation of the H-lignin by treatment with hydrogen peroxide apparently rendered the H-lignin more available to *S. purpureum* or split out compounds from the lignin molecule which could be utilized. If it is assumed that the "oxidized-lignin" contained 50% carbon, which is probably too high, then it was decomposed approximately 30%.

SUMMARY AND CONCLUSIONS

Lignin, xylan, and cellulose were extracted from oat straw and used in comparison with oat straw as sources of carbon for some common soil molds in a series of five experiments. "Ca-lignin" and an "oxidized-lignin" were prepared and used as sources of carbon for comparison with H-lignin for *Stereum purpureum* in a sand culture medium. H-lignin was very resistant to aerobic decomposition but was slightly decomposed by a soil infusion in solution cultures and by *S. purpureum* in a sand culture medium. The "oxidized-lignin" was less resistant to decomposition by *S. purpureum* than H-lignin.

It was concluded that lignin does not possess antiseptic properties and though it may decompose slowly, it gradually disappears from soils.

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THE MINERAL CONTENT OF SOIL TYPES AS RELATED TO "SALT SICK" OF CATTLE[1]

O. C. BRYAN AND R. B. BECKER[2]

HILGARD (16)[3] first pointed out in a systematic way a definite relationship between native vegetation and soil types in North America. While his observations have been confirmed generally by later workers, the relation between soil types and the health of animals grazing thereon has not been defined so clearly. This has been due partly to a lack of refinement in chemical methods and partly to the fact that animals range more widely in their search for food nutrients than is possible with individual plants.

The disease of cattle known as "salt sick" has been an age-old problem in parts of Florida with cattle grazing over certain types of soils. It has been studied intermittently by members of the Florida Agricultural Experiment Station staff for over 40 years. Corrective measures finally were discovered and applied by Becker, Neal, and Shealy (9) in 1930. According to them, salt sick is a nutritional anemia of animals, due to insufficient amounts of copper and iron in the feed. It seems to be associated with certain types of sandy and peat soils on which forage crops contain less iron than do the same class of forages on healthy soil areas. A number of local names are applied to the disease or condition, corresponding to the character of the local ranges where it occurs, namely, scrub sick, hill sick, marsh sick, prairie sick, bay sick, salt sick, and just plain sick.

A condition similar to salt sick of livestock, sometimes called progressive or nutritional anemia and arising from the lack of certain minerals in feeds and soils upon which animals graze, is known to occur in New Zealand (2, 3, 5, 6, 7), southern Scotland (12), Kenya Colony in East Africa (18), and King's Island, Tasmania (13). This disease is known locally as bush sickness in New Zealand, Nakuruitis in Kenya Colony, and vinquish, daising, pining or pine in Scotland, and according to Aston (7), is identical with salt sick of Florida. Although iron supplement in the feed has been a satisfactory curative in many cases, there have been some striking exceptions. This is confirmed by the fact that Becker, *et al.* (9) found it necessary to add small amounts of copper to the iron supplement in correcting the condition with salt sick animals.

Although field surveys (1929) indicated that the salt sick problem in Florida was more prevalent on certain light sandy soils than on heavier soils, no definite correlation of the disease with specific soil types had been established. The object of this investigation was to

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[3]Figures in parenthesis refer to "Literature Cited," p. 127.

determine to what extent soil types and composition of soils influenced the occurrence and distribution of salt sick on Florida ranges.

PLAN OF STUDY

Composite soil samples from at least three separate borings were collected from 21 mineral soils and 2 peat soils, representing typical areas on which range cattle were known to develop salt sick, and from 17 healthy mineral soils on which range cattle were known to remain free from salt sick. These areas had been located by the junior author and co-workers in the Department of Animal Husbandry of the Florida Experiment Station for the purpose of studying the condition in cattle in relation to the composition of range grasses. In all cases virgin soils were collected to a depth of 4 feet and stored in glass jars by foot depths.

After drying, the soils were sieved through cloth screens and ground in an agate mortar to avoid metal contaminations. Standard methods of procedure by acid extraction (4) were used to determine the calcium, phosphorus, and iron. From 5 to 40 grams of soil (80-mesh), depending on clay content, were ignited in a muffle furnace at 450° before digesting with a 1 to 1 solution of hydrochloric acid to which small amounts of nitric acid had been added. The solutions were boiled for 10 minutes and then evaporated on a steam bath until dry. Additional amounts of acid were added and again evaporated to dryness on a steam bath, and the residue taken up in hot solution of dilute hydrochloric acid and stored in volumetric flasks for analysis. This procedure appeared to give complete extraction of the metals in sands. Silt and clay determinations were made by the Bouyoucos method (11).

Since the earlier studies with cattle showed that copper and iron supplements prevented salt sick (9), it was thought desirable to determine these elements in the soils in addition to the calcium and phosphorus. Controls were included in all cases to ascertain the impurities in the reagents. Impurities were found often in determinable amounts even with the best of C. P. reagents. The pyridine method (14) proved to be the most satisfactory procedure for determining copper in soils. It was necessary to remove the iron by double precipitation before determining the copper. Results of these analyses are tabulated in Tables 1 and 2 in conjunction with the soil types. Analyses were made of the third foot of soils, but since they are in the same order as those in the first and second feet, they are not included in the tables. The amount of silt and clay also was determined, and the results included in the tables for comparison.

A preliminary study has been begun of the effects upon the growth of mustard plants obtained by applying amendments to certain of these soils.

RESULTS AND DISCUSSION

Examination of the data in Tables 1 and 2 shows that the salt sick areas consist of sands and fine sands of the Leon, Portsmouth, Dade, and Norfolk series and also peat deposits. The healthy areas consist of fine sandy loams or sands with clay subsoils of the Bladen, Gainesville, Hernando, Fellowship, Orangeburg, Lakewood, and Norfolk series. The soils in the healthy areas contained over twice as much silt and clay (9.9%) as did those in the salt sick areas (4.3%) in the first foot and over three times as much (15.2% as against 4.4%) in the second foot. The Norfolk soils have a wide range of types and phases which vary greatly in texture and natural fertility. This fact

seems to account for this group of soils occurring in both the salt sick and the healthy ranges. The Lakewood sand has a bright yellow sub-

TABLE 1.—*Mineral composition of first foot of Florida soils as related to "salt sick" of cattle.*

Soil type	Calcium %	Phosphorus %	Iron %	Copper, p.p.m.	Silt and clay %	pH values
			"Salt Sick" Areas			
Dade sand..........	0.109	0.003	0.012	5.71	2.9	6.59
Leon sand...........	0.040	0.013	0.014	1.96	5.5	4.72
Leon sand...........	0.021	0.004	0.030	2.43	5.0	4.65
Leon sand...........	0.022	0.003	0.018	2.01	1.8	4.55
Leon sand...........	0.021	0.006	0.007	1.61	2.8	4.59
Leon fine sand.......	0.010	0.006	0.056	4.51	6.0	4.91
Leon sand...........	0.042	0.005	0.013	3.15	2.2	4.93
Leon sand..........	0.017	0.004	0.071	5.00	4.3	5.28
Portsmouth sand.....	0.017	0.014	0.023	7.85	5.4	4.55
Portsmouth fine sand.	0.021	0.004	0.011	6.03	4.5	4.41
Portsmouth fine sand.	0.121	0.007	0.069	2.87	3.4	6.76
Norfolk fine sand.....	0.031	0.007	0.054	3.42	7.5	5.07
Norfolk sand.........	0.041	0.010	0.043	4.62	4.3	5.68
Norfolk fine sand.....	0.042	0.030	0.067	3.18	8.9	5.46
Norfolk sand.........	0.027	0.070	0.055	2.81	1.7	4.95
Norfolk fine sand.....	0.052	0.011	0.086	1.50	3.9	6.00
Norfolk sand.........	0.026	0.015	0.041	4.49	4.2	4.97
Norfolk fine sand.....	0.018	0.009	0.026	5.11	3.7	4.85
Norfolk fine sand.....	0.027	0.018	0.065	5.01	2.8	5.01
Norfolk sand.........	0.022	0.007	0.061	5.26	5.4	4.98
Norfolk sand.........	0.025	0.015	0.014	4.84	4.8	5.62
Average...........	0.036	0.012	0.040	3.97	4.3	5.17
			Healthy Areas			
Bladen fine sand......	0.025	0.008	0.124	5.05	4.9	5.00
Bladen fine sand......	0.037	0.003	0.134	11.52	10.7	5.19
Fellowship sandy loam	1.789	0.331	1.266	18.10	25.2	5.68
Gainesville fine sand..	0.052	0.008	0.203	4.21	6.0	5.37
Hernando sandy loam.	0.206	0.070	0.544	5.07	7.6	6.19
Hernando sand.......	0.041	0.005	0.082	6.98	5.0	4.93
Lakewood sand......	0.019	0.009	0.077	2.42	1.1	5.40
Norfolk loamy sand...	0.072	0.114	0.555	7.39	15.6	5.33
Norfolk fine sand.....	0.042	0.005	0.232	8.37	6.4	4.84
Norfolk sand.........	0.020	0.005	0.112	10.47	7.6	5.54
Norfolk fine sand.....	0.050	0.005	0.077	7.19	7.1	4.66
Norfolk fine sand.....	0.030	0.009	0.079	8.10	7.0	4.87
Norfolk fine sand.....	0.034	0.003	0.141	20.97	10.4	5.03
Orangeburg loamy sand.............	0.106	0.015	0.768	6.46	15.6	5.03
Orangeburg fine sandy loam........	—	0.178	1.445	9.36	19.3	5.10
Orangeburg fine sand	0.055	0.040	0.601	5.74	7.6	5.46
Ruston loamy sand...	0.014	0.156	0.733	8.20	10.6	5.34
Average	0.162	0.057	0.422	8.56	9.9	5.24
			"Salt Sick" Areas on Peat			
Peat................	3.398	0.029	0.743	42.30	—	5.74
Peat................	1.079	0.025	0.277	12.75	—	4.68
Average...........	2.239	0.027	0.510	27.53	—	5.27

soil with a higher content of iron than do most of the other sands, but a rather low content of silt and clay, as shown in the tables. This

TABLE 2.—*Mineral composition of second foot of Florida soils as related to "salt sick" of cattle.*

Soil type	Calcium %	Phosphorus %	Iron %	Copper, p.p.m.	Silt and clay %	pH values
			"Salt Sick" Areas			
Dade sand	0.261	0.006	0.183	0.27	3.4	7.43
Leon sand	0.011	0.004	0.038	0.81	5.2	4.35
Leon sand	0.006	0.001	0.026	0.37	4.6	5.41
Leon sand.	0.001	0.008	0.014	0.86	2.0	5.18
Leon sand...	0.006	0.002	0.017	0.22	3.8	5.84
Leon fine sand	0.002	0.003	0.184	1.40	4.8	4.66
Leon sand	0.150	0.002	0.008	0.66	2.4	5.72
Leon sand	0.008	0.003	0.026	1.29	4.4	4.95
Portsmouth sand	0.008	0.013	0.047	0.27	3.6	4.76
Portsmouth fine sand ..	0.003	0.002	0.008	0.93	4.6	5.04
Portsmouth fine sand..	0.086	0.002	0.029	0.72	1.6	6.17
Norfolk fine sand	0.004	0.003	0.124	1.44	7.6	5.09
Norfolk sand	0.006	0.008	0.050	1.85	3.8	5.55
Norfolk fine sand	0.006	0.004	0.124	1.69	8.4	5.32
Norfolk sand.	0.016	0.011	0.065	0.81	4.4	5.06
Norfolk fine sand	0.001	0.004	0.101	2.00	3.4	5.42
Norfolk sand	0.003	0.007	0.053	1.22	5.2	5.23
Norfolk fine sand	0.002	0.004	0.047	1.32	4.4	5.16
Norfolk fine sand	0.013	0.018	0.107	0.84	3.0	5.52
Norfolk sand	0.005	0.009	0.091	1.65	7.0	4.96
Norfolk sand	0.016	0.013	0.161	1.81	5.2	5.29
Average	0.029	0.006	0.072	1.07	4.4	5.27
			Healthy Areas			
Bladen fine sand	0.006	0.004	0.160	2.02	5.0	4.60
Bladen fine sand	0.036	0.002	0.842	1.66	21.6	5.13
Fellowship sandy loam	1.085	2.687	2.508	6.20	—	5.31
Gainesville fine sand	0.011	0.045	1.899	5.96	27.2	4.58
Hernando sandy loam	0.102	0.190	0.972	2.34	16.0	5.37
Hernando sand	0.066	0.004	2.514	2.95	15.6	5.55
Lakewood sand....	0.001	0.008	0.177	0.58	1.6	4.90
Norfolk loamy sand	0.007	0.060	0.675	6.73	11.4	4.71
Norfolk fine sand..	0.016	0.013	0.714	7.04	10.6	5.34
Norfolk sand. .	0.029	0.004	0.180	3.35	7.2	5.11
Norfolk fine sand .	0.011	0.002	0.156	1.39	7.0	5.53
Norfolk fine sand .	0.008	0.010	0.204	1.22	7.4	5.16
Norfolk fine sand .	0.009	0.013	0.356	1.61	14.2	4.61
Orangeburg loamy sand	0.041	0.002	5.506	3.76	48.4	4.55
Orangeburg fine sandy loam	0.021	0.061	1.791	2.85	26.8	5.41
Orangeburg fine sand	0.190	0.050	0.723	11.11	8.8	5.09
Ruston loamy sand	0.020	0.050	0.792	3.31	15.0	5.23
Average	0.098	0.189	1.186	3.77	15.2	5.07
			"Salt Sick" Areas on Peat			
Peat	0.714	0.012	0.740	26.68	—	6.75
Peat	1.074	0.022	0.401	2.72	—	5.53
Average . . .	0.894	0.017	0.571	14.70	—	6.20

higher content of iron seems to account for this type being in the healthy group of range soils.

In general, the results show that the healthier soils contained higher amounts of silt and clay regardless of series, but in no case examined were the Leon and Portsmouth sands and fine sands in the healthy areas. These results seem to be in agreement with those of New Zealand regarding soil texture (5). Both areas of peat examined were subject to salt sick.

The data in Tables 1 and 2 also show some interesting correlations between the amount of mineral matter in the salt sick areas as compared with the healthy areas. The surface foot of healthy range soils contained an average of 0.162% of calcium, 0.057% of phosphorus, 0.422% of iron, and 8.56 p. p. m. of copper, while the salt sick soils contained 0.036% of calcium, 0.012% of phosphorus, 0.040% of iron, and 3.97 p. p. m. of copper.

While the results are not always consistent from soil to soil, the average results are rather positive. The surface foot of the soils of the healthy range areas contained approximately 10 times as much iron, 2 times as much copper, and 5 times as much calcium and phosphorus as did the soils from the salt sick areas. With few exceptions, the salt sick soils contained less copper and iron than did the healthy range soils. It may be noted that all of these soils are low in calcium and phosphorus, with one or two exceptions. The content of iron increased from the first to the second foot, but that of calcium and phosphorus decreased on the salt sick areas. At the same time that the phosphorus decreased on the salt sick areas it increased on the healthy areas. This may be explained on the assumption that the greater part of the iron existed in the clay or mineral portion of the soil, while the calcium and copper were more concentrated in the organic matter. Both of the peat soils contained comparatively high amounts of copper and iron. These peat soils were not subject to overflow from healthy range areas.

The results of this study, together with those of Neal and Becker (17), indicate that the composition of the soil has a definite influence on the composition of plants. This has been borne out by the work in New Zealand (2, 5) with soils on which bush sickness develops.

It is interesting to point out that the soils of Florida contain less iron than do those from New Zealand. It is also significant that Florida soils contain less calcium and phosphorus than do the New Zealand soils, according to the hydrochloric acid extraction method. No reports of copper were made on the soils from these other countries. In most cases, the New Zealand soils (5) contain several times more available iron (citric acid extract) than that of the total content in the salt sick soils of Florida. It appears that the iron in mineral soils of Florida is more available to plants than is the case with the soils of New Zealand. Results obtained by Allison, *et al.* (1) show that copper is not available on the raw peat soils of the Florida Everglades.

It is possible that the acid extraction method may show slightly lower results than does the fusion method. However, it is extremely doubtful whether the differences would be significant with marine sands which possess such a low content of silt and clay.

From the results of this study, it would be reasonable to assume that the St. Lucie, St. Johns, and Plummer soils would be subject to salt sick in cattle. Moreover, the results explain the observations and practices of cattlemen in different areas of the state. They have found it necessary for years to transfer salt sick animals to healthy ranges, sometimes known locally as "hospital" lands, in order to avoid loss. Where this practice was observed, the so-called hospital lands have been either on sandy loam or on one with a sandy clay strata from 15 to 30 inches below the surface. These healthy soils contained more iron and other minerals than did the deep sands, and according to Neal and Becker (17), vegetation growing on these healthy range soils contained more iron than did that on the salt sick areas.

The fact that salt sick occurs on both calcareous and low-lime soils bars it from being related to calcium deficiency. However, highly calcareous soils often reduce the solubility of the iron and thereby may tend to induce salt sick sooner. This is confirmed by observations in New Zealand (5). It is possible that the low content of phosphorus and calcium in the soil hinders normal plant development and that the incidence and severity of salt sick among animals may be modified by the general plane of nutrition which involves elements other than copper and iron. Salt sick areas are known to overlap onto areas where cattle also suffer from phosphorus deficiency (8, 9).

APPLICATION OF SOIL AMENDMENTS

Since the soils on which cattle were known to develop salt sick contained less copper than did those on healthy areas, it was thought advisable to determine the effects on the response of plants obtained by adding copper salts to these soils under controlled conditions Mustard was chosen as an index plant for this purpose because of its rapid habits of growth and the ease of handling it under greenhouse conditions.

Uniform amounts of a virgin soil from a healthy range area and similar amounts representing a salt sick area were placed in 2-quart glazed earthenware jars in the greenhouse. These soils were then given uniform treatment of a complete fertilizer, including iron, manganese, and zinc. Copper sulfate was added in amounts varying from 0.5 to 10 p. p. m., and the soils planted to mustard. They were moistened with tap water as needed and the plants allowed to grow. The relative amounts of mustard on the two soils at the end of 40 days are shown in Fig. 1.

It may be observed from the rates of growth of the mustard plants on the Leon sand—a salt sick soil—that there was a decided response to the copper treatments, while very little response was noted on Gainesville fine sand—a healthy range soil. These results further support the data in Tables 1 and 2 in that the salt sick soils are deficient in copper even for the growth of certain plants. A number of other soils were treated for copper and iron stimulation, the results of which are being reported in a separate paper.

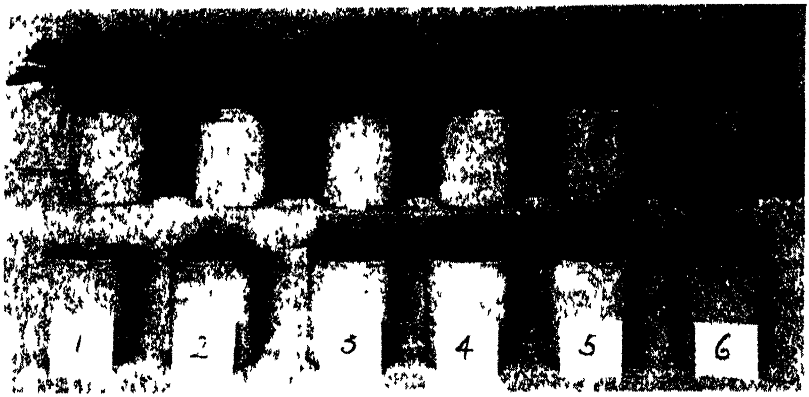

FIG. 1.—The effect of copper sulfate on a "salt sick" soil.

Upper, Gainesville fine sand, a healthy soil; *lower*, Leon sand, a "salt sick" soil Culture No. 1 received no copper; cultures Nos. 2, 3, 4, 5, and 6 received 0.5, 1, 2, 5, 5, and 10 p p.m., respectively, of copper sulfate on both soils; all other factors held constant

SUMMARY

A study was made of 40 range soils of Florida, 21 of which were mineral soils and 2 organic soils on which cattle were known to develop salt sick. Seventeen were mineral soils on which cattle were known to remain healthy. These soils were classified into types and analyzed for total calcium, phosphorus, iron, and copper. Some of the representative soils were treated with varying amounts of copper sulfate and planted to mustard

The results may be summarized as follows

1. The salt sick soils consisted of sands and fine sands of the Leon, Portsmouth, Dade, and Norfolk series

2 The healthy range soils consisted of the sandy loams and sands of the Bladen, Fellowship, Hernando, Gainesville, and Orangeburg soils, and also the Norfolk soils with sandy loam or clay subsoil.

3. The surface soil of the healthy ranges contained approximately 10 times as much iron, 2 times as much copper, 5 times as much phosphorus, and 5 times as much calcium as did those of the salt sick areas.

4. The organic soils contained relatively higher amounts of calcium, iron, and copper than did the mineral soils, yet they were subject to salt sick.

5. Cattle will develop salt sick on soils with 0.036% of iron and 3.85 p. p. m. of copper, while they remain healthy upon soils with 0.42% of iron and 8 p. p. m. of copper.

6. Additions of copper sulfate to the salt sick soils increased the growth of mustard under controlled conditions.

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THE EFFECTS OF INOCULATION AND FERTILIZATION OF SPANISH PEANUTS ON ROOT NODULE NUMBERS[1]

J. F. DUGGAR[2]

EXAMINATION of Spanish peanut plants growing on a number of farms in the eastern and central parts of Alabama showed a surprisingly small number of root nodules. Hence experiments were made in 1930, 1931, and 1932 with Spanish peanuts to ascertain whether such scant nodulation would continue under known conditions and whether it would be corrected by artificial inoculation of seed or by the application of certain well-known fertilizers. The main objectives have been to determine to what extent inoculation and fertilization would affect the number of nodules per plant and to ascertain to what extent an increase in nodule numbers through inoculation or fertilization would influence yields of Spanish peanuts.

METHODS AND CONDITIONS

In the experiments here reported unhulled Spanish peanuts were planted on Norfolk soils about 2 miles south of Auburn, Ala. Artificial inoculation was effected by soaking the unhulled seeds for about an hour in a suspension of pure cultures made from peanut nodules. The fertilizer was drilled about 3 inches deep; and, unless otherwise stated, it was carefully mixed with the soil to avoid immediate contact with the planted peanuts. Counts of nodules were made at intervals on many plants, which were collected from a number of scattered locations on each plat.

In the counts made in the latter part of the growing season it was practicable to determine, in addition to the number of total nodules, also the number of large nodules. The latter were arbitrarily taken as those nodules having a maximum diameter equal to or greater than that of an average matured seed of hairy vetch.

In the summer of 1932 the rainfall was ample, but in 1930 and 1931 periods of severe drought occurred.

RESULTS

EFFECTS OF ARTIFICIAL INOCULATION

Table 1 shows the number of nodules, both total and large, on unfertilized Spanish peanut plants at successive dates in 1930, 1931, and 1932.

Nodules of all sizes were relatively much more abundant on the plants grown from inoculated than on those from untreated seed. This held true for at least 18 out of the 19 comparisons shown in the above table. Without artificial inoculation, unfertilized, nearly mature Spanish peanut plants averaged scarcely eight *total* nodules and fewer than three *large* nodules. That such few nodules were insufficient for optimum growth of the plant is indicated by generally low yields of both mature nuts and entire dry plants.

[1]Contribution from the Department of Special Investigations, Alabama Agricultural Experiment Station, Auburn, Ala. Received for publication December 10, 1934.

[2]Research Professor.

TABLE 1.—*Number of root nodules per peanut plant, with and without inoculation, in 1930, 1931, and 1932.*

Date of planting	Average number of nodules at plant age of									
	22–23 days		27–32 days		41–48 days		67–85 days		106–113 days	
	No inoculation	Inoculated	No inoculation	Inoculated	No inoculation	Inoculated	No inoculation	Inoculated	No inoculation	Inoculated
	Average Number of Total Nodules per Plant									
June 12, 1930	0.1	1.1	0.3	1.9	2.9	7.5	10.6	14.2	10.9	28.4
July 11, 1931	0.8	7.1	3.2	7.2	—	—	11.3	8.8	7.1	13.0
May 24, 1932	0.4	1.4	—	—	0.4	13.2	3.6	23.7	5.7	51.2
3-year av.	0.4	3.2	1.7*	4.5*	1.6*	10.4*	7.5	15.6	7.9	30.9
	Average Number of Large Nodules per Plant									
June 12, 1930	—	—	—	—	—	—	1.1	9.5	2.7	10.9
July 11, 1931	—	—	—	—	—	—	3.1	4.6	1.5	5.7
May 24, 1932	—	—	—	—	—	—	0.3	10.5	2.4	19.8
3-year av.	—	—	—	—	—	—	1.5	8.2	2.2	12.2

*Average for 2 years.

EFFECT OF INOCULATION ON NODULE NUMBERS AND YIELDS FOLLOWING VARIED FERTILIZATION

In 1930, inoculation of unhulled Spanish peanut seed intensified nodulation and was followed by an increase of 16% in yield of nuts per plant. In 1931, the increase in yield of nuts ascribed to artificial inoculation alone, with its increased nodulation, was 71% on the unfertilized series and 20% on the series of plats that received basic slag. The unweighted average for 3 years showed a gain from inoculation with peanut cultures of 40% in yield of nuts per plant in the absence of any fertilizer.

Table 2 shows the average number of nodules per plant at the final harvest in 1932, and the yields of dry nuts per plant where various fertilizers had been drilled in and mixed with the soil just before planting unhulled Spanish peanuts, both with and without inoculation.

TABLE 2.—*Numbers of nodules at harvest and yields of inoculated and non-inoculated Spanish peanut plants receiving different fertilizer treatments in 1932.*

Fertilizer, lbs. per acre	Total nodules per plant		Large nodules per plant		Yield of dry nuts, grams per plant		Increase in yield from inoculation, %
	Not inoculated	Inoculated	Not inoculated	Inoculated	Not inoculated	Inoculated	
None.	5.7	51.2	2.4	19.2	10.0	13.4	33
600 lbs. basic slag phosphate	4.7	62.0	1.7	22.6	10.8	16.7	54
400 lbs. superphosphate	9.0	65.1	3.6	19.3	11.9	16.7	40
400 lbs. hydrated lime	13.7	70.3	6.1	18.1	17.7	19 0	7
50 lbs. muriate of potash, 400 lbs. hydrated lime, and 600 lbs. basic phosphate	13.7	84.1	8.1	41.2	17.4	20.2	16
50 lbs. sulfur, 400 lbs. hydrated lime, and 600 lbs. basic slag phosphate	7.0	61.6	2.1	22.3	13.9	17.9	29
Av. of 6 conditions	9.0	65.7	4.0	23.8	13.6	17.3	30

Inoculation of unhulled seed resulted in a very large increase in nodule numbers, regardless of fertilization. Inoculation afforded, on the average, a six-fold increase in total nodules, a five-fold increase in large nodules, and a 30% increase in yield of nuts.

In the favorable season of 1932 each of the fertilizers significantly increased the yields of dry nuts where the fertilizer did not come into immediate contact with unhulled seed.

EFFECT ON NODULATION AND YIELD FROM CONTACT BETWEEN FERTILIZERS AND SEED PEANUTS

It seemed desirable to ascertain what effects, if any, on nodule numbers and yields would result if the fertilizers should be so applied as to come into immediate contact with the seed, as might occur to some extent in careless farm practice. The fertilizers were separately drilled in uncovered furrows, but on top of and in immediate contact with the unhulled seed, and at the same rates as in the preceding experiments. The contact between seed and fertilizer was further raised to the maximum by a pre-planting treatment consisting of wetting the unhulled nuts with tap water and then rolling them in a small part of the appropriate fertilizer.

Most of the chemicals when thus applied caused significant reductions in final nodule numbers and yields. Leading in depressive effect on nodule numbers were separate applications of superphosphate and muriate of potash when thus wrongly placed. Also distinctly depressive to nodule numbers were misplaced land plaster and 100 pounds per acre of manganese sulfate. Hydrated lime so used seemed either slightly depressive or without significant effect. Even basic slag in close contact with unhulled seed in the dry summer of 1931 failed to exercise a favorable effect on nodulation or yield. Most chemicals that notably depressed nodule numbers also reduced the yield of dry nuts per plant. Such unfavorable effects of misplaced fertilizers were in direct contrast with the favorable effects from certain fertilizers properly placed, as discussed in earlier paragraphs.

CORRELATION BETWEEN NUMBERS OF NODULES AND YIELDS OF SPANISH PEANUTS

Both in 1931 and 1932 the average numbers of nodules on Spanish peanut plants were found under most conditions to be significantly and positively related to the average yield of nuts per plant. The correlation coefficient expressing this relationship between number of *total* nodules at harvest time and yield of dry nuts was calculated as $+ .43 \pm .114$ for the averages from each of the 23 variously treated plats planted in May, 1931, and as $+ .68 \pm .096$ for those of the plats variously fertilized in 1932.

Significant and positive were also the relationships between average nut yields and numbers of total nodules that had been found on the blooming plants 49 and 38 days before the final harvest, following varied fertilization and seed treatment. In 1931, the correlation coefficient for total nodules 49 days before harvest in relation to final yields of nuts was $+ .64 \pm .083$. In 1932, it was $+ .65 \pm .099$ for the total nodules as found 38 days before harvest. Thus, in both years, nodule numbers as counted weeks before digging the crop served as rough indications of the relative prospective yields.

In Table 3 are shown the correlation coefficients between nodule numbers at the final harvest date in 1932 and the corresponding average yields of nuts on the *inoculated* plants variously fertilized without contact between seed and fertilizers.

TABLE 3.—*Correlation coefficients showing relation at date of harvest between average number of nodules (total and large) per inoculated plant, variously fertilized, and average yield of dry unhulled peanuts per plant, 1932.*

Fertilizer, lbs. per acre	Number of plants	Coefficient for total nodules and yield	Coefficient for large nodules and yield
None	35	+0.60±.073	+0.59±.040
600 lbs. basic slag phosphate	29	+.30±.113	+.48±.096
400 lbs. superphosphate in drill	36	+.49±.027	+.72±.042
400 lbs. superphosphate near surface	32	+.42±.089	+.61±.035
400 lbs. hydrated lime	24	+.42±.113	+.58±.081
400 lbs. hydrated lime and 600 lbs. basic slag phosphate	37	+.42±.091	+.54±.083
50 lbs. muriate of potash, 400 lbs. hydrated lime, and 600 lbs. basic slag phosphate	33	+.43±.095	+.82±.018
50 lbs. sulfur, 400 lbs. hydrated lime, and 600 lbs. basic slag phosphate	36	+.64±.066	+.77±.045

For each of the plats in the inoculated series the correlation between numbers of *large* nodules per plant and yields of nuts was invariably high and positive and was only moderately altered by the character of the fertilization. This correlation was highest (+ .82 ± .018) on the plants receiving a mixture of potash, lime, and basic slag phosphate.

Generally significant, but somewhat less close, was the relationship on the inoculated series between number of *total* nodules and yield of peanuts.

When nodule numbers were severely restricted by the absence of artificial inoculation, the only correlation coefficient that appeared to be significant was that for the plants receiving a mixture of potash, lime, and basic slag phosphate. This was + .53 ± .092 for total nodules and + .53 ± .091 for large nodules in relation to yield of nuts.

In brief, the correlation data for 2 years indicated that yields of dry nuts per plant tended to increase as numbers of either total or large nodules increased, both as determined at harvest and at a somewhat earlier date. In each year some exceptions occurred where highly unfavorable conditions for plant growth were encountered, including extreme drought and very late planting.

SUMMARY

Spanish peanut plants were found in experiments at Auburn and also on certain sandy soils elsewhere outside of the commercial peanut belt to develop naturally only a scant supply of root nodules.

Artificial inoculation of unhulled seed resulted in large increases in the numbers of both total and large nodules and in average increases of 40 and 30% in yield of nuts per plant.

Artificial inoculation increased nodule numbers and yields in the presence of nearly all of the common fertilizers tested when they did

not come in contact with the unhulled seed. On the other hand, most common fertilizers when applied in *maximum* contact with the unhulled seed in a dry summer reduced the number of total and large nodules and the yields of nuts.

Significant positive correlation was generally found between numbers of either total or large nodules per plant and yield of dry peanuts per plant where conditions were favorable for crop growth. This held true both for numbers of nodules present at the final harvest and also for the numbers found several weeks earlier.

TOXICITY OF SEVERAL CHEMICALS TO A SPECIES OF MOSS COMMON TO OLD PASTURES IN THE NEW ENGLAND STATES[1]

A. B. BEAUMONT[2]

RECENTLY, the writer (1)[3] called attention to the toxicity of sodium nitrate to a species of moss (*Polytrichum commune* L) found in upland pastures of Massachusetts. This species is one of the last to appear in the natural succession of pasture plants concurrent with the depletion of plant nutrients from the soil.

PLAN OF EXPERIMENT

In order to study the effect of other materials on this species of moss, a series of small plats was laid out in the spring of 1931. The plat treatments are listed in Table 1, and those numbered 1 to 9, inclusive, constitute series 1. These plats received nitrogen materials in quantities to supply 30 pounds and 60 pounds of nitrogen per acre, respectively, and the other materials were applied in chemically equivalent amounts. The effects of the materials of series 1 soon indicated that the different ions of the compounds used were more or less specific in their toxic action on haircap moss. Therefore, in 1932, a second series of plats (treatments 10 to 17, inclusive) was laid out adjacent to or near the first series, for the purpose of studying other ionic combinations. All plat treatments were duplicated. Plats of series 1 were 10 by 10 feet and those of series 2, 5 feet by 10 feet. Treatment of all plats was omitted in 1933 but was repeated in 1934. Therefore, plats of series 1 received three applications of materials and those of series 2 received two applications in the period of 1931 to 1934. At the beginning of the experiment the areas treated had a ground vegetation cover consisting of 85% to 95% haircap moss and small percentages of bent grasses, Kentucky bluegrass, "poverty" grass, hard hack (*Spiraea tomentosa* L), running cinquefoil (*Potentilla canadensis* L), and other weeds. The soil is a well-drained glacial till classed as Cheshire fine sandy loam, stony phase.

RESULTS AND DISCUSSION

In the fall of 1934 an estimate of the percentage of eradication of haircap moss was made and samples of soil taken for laboratory studies. The average percentage eradication of moss for each treatment is given in Table 1.

It is apparent that wide differences in the degree of eradication of the moss were obtained. Eradication was greater with the larger amount of material used in every case, but with few exceptions practically the same order prevailed among materials used. Sodium nitrate was the most effective material used, but a strict comparison between this material and those of series 2 is not possible because of the difference in the number of applications made. No significant difference in the effect of the Chilean and synthetic nitrates was ob-

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[1]Contribution from the Department of Agronomy, Massachusetts State College, Amherst, Mass. Contribution No. 210, Massachusetts Agricultural Experiment Station. Received for publication December 8, 1934.

[2]Professor.

[3]Figures in parenthesis refer to "Literature Cited," p. 137.

TABLE 1.—*Percentage eradication of moss and reaction of soil.*

Plat No.	Treatment	30-lb. nitrogen equivalent				60-lb. nitrogen equivalent			
		Eradication		Soil reaction		Eradication		Soil reaction	
		%	Rank	pH	Rank	%	Rank	pH	Rank
1	Ammonium sulfate (synthetic)	18	9	4.65	2	60	7	4.3	1
2	Calcium cyanamide (Cyanamid)	13	10	4.8	4	65	6	4.7	4
3	Calcium nitrate	8	12	4.8	4	35	9	4.8	5
4	Sodium nitrate (Chilean)	63	2	4.95	6	93	2	5.2	9
5	Sodium nitrate (synthetic)	65	1	4.9	5	95	1	5.15	8
6	Potassium chloride	40	6	4.6	1	93	2	4.8	5
7	Potassium nitrate	30	8	4.9	5	88	4	5.1	7
8	Sodium chloride	50	5	4.6	1	93	2	4.6	2
9	Urea	0	14	4.6	1	13	13	4.6	2
10	Ammonium carbonate	0	14	4.6	1	20	10	4.8	5
11	Ammonium chloride	55	4	4.6	1	90	3	4.7	4
12	Ammonium nitrate	3	13	4.7	3	18	11	4.65	3
13	Potassium carbonate	35	7	4.8	4	70	5	4.9	6
14	Potassium sulfate	10	11	4.9	5	55	8	4.8	5
15	Sodium acetate	60	3	5.0	7	93	2	5.6	11
16	Sodium carbonate	30	8	5.3	8	93	2	5.55	10
17	Sodium sulfate	8	12	4.7	3	15	12	4.7	4
18	Check (1–9)	—	—	4.6	1	—	—	4.6	2
19	Check (9–11)	—	—	4.8	4	—	—	4.8	5

tained. Generally, sodium compounds were the most effective in elimination of the moss, followed in order by compounds of potassium, calcium, and ammonium, but the specific effectiveness of a given compound depended on its anion as well. From the results obtained the ions of the compounds used in more than one combination are tentatively grouped in respect to their eradicating power as follows:

$$Na > K > Ca > NH_4$$
$$NO_3 > Cl > SO_4 > CO_3$$

This arrangement of ions suggests the lyotropic series. With some exceptions, eradicating power of combinations of ions agreed with the order given. Not all possible combinations of the above ions were used in the experiments here reported, but those combinations not used have been used in other pasture experiments in recent years. In other experiments calcium sulfate and calcium carbonate have shown no direct toxic action on haircap moss. In Table 2 materials used in the present experiment are grouped according to their eradicating power, and calcium sulfate and calcium carbonate would fall in the "low" group, as would superphosphate also.

As has been pointed out in a previous (2) paper, the toxic action on haircap moss here considered is direct and should not be confused with the indirect eradication of this plant by competitive crowding. Under the influence of certain fertilizer materials, themselves innoc-

uous to haircap moss, certain grasses, clovers, and other vegetation will in time eliminate this moss by crowding. Directly toxic materials, such as sodium and potassium nitrates and chlorides, more or less immediately kill the moss, as is evident by the presence of large areas of the dead material some time after the application of the salts. In the experiments here considered the vegetation which eventually replaced the moss consisted largely of bent grasses. Only in the case of treatments with sodium carbonate and sodium acetate did any considerable proportion of weeds replace the moss.

TABLE 2.—*Fertilizer materials and other chemicals grouped according to their power of eradicating haircap moss.*

30-lb. N equivalent	60-lb. N equivalent
High Eradicating Power	
Sodium nitrate (Chilean)	Sodium nitrate (synthetic)
Sodium nitrate (synthetic)	
Sodium acetate	
	Sodium nitrate* (Chilean)
	Sodium chloride
Ammonium chloride	Potassium chloride
	Sodium carbonate
	Sodium acetate
Sodium chloride	Ammonium chloride
	Potassium nitrate
Medium Eradicating Power	
Potassium chloride	Potassium carbonate
Potassium nitrate	Calcium cyanamide
Potassium carbonate	Ammonium sulfate
Sodium carbonate	Potassium sulfate
Ammonium sulfate	
Calcium cyanamide	
Low Eradicating Power	
Potassium sulfate	Calcium nitrate
Sodium sulfate*	Ammonium carbonate
Calcium nitrate	Ammonium nitrate
Ammonium nitrate	Sodium sulfate
Ammonium carbonate*	Urea
Urea	

*Bracketed compounds ranked equally in eradicating power.

In a preliminary study of the cause of the toxic effects here reported, consideration was given the effect of the materials used on the soil reaction. Samples of soil were drawn in the fall of 1934 and tested for reaction with the quinhydrone electrode. The pH values for the different treatments are given in Table 1. It may readily be seen that there is no direct correlation between the eradicating power of the materials used and the soil reaction induced by them. For example, in the larger amount ammonium sulfate produced the most acid soil, but it ranked in the middle group as an eradicator of moss; sodium chloride and urea had no effect on soil reaction, but the former ranked high and the latter low in eradicating power; sodium nitrate, sodium carbonate, and sodium acetate were high in eradicating power and raised the reaction of the soil considerably, but in an adjacent experi-

ment where 6,960 pounds of ground limestone had been applied within 10 years and the reaction of the soil had been raised to pH 6.2, haircap moss was abundant.

It appears that the explanation of the ecological relationships of haircap moss revealed by these experiments must be sought primarily in the physiology of the plant. Most likely, absorption and adsorption of ions by the colloidal complex of the soil and the selective absorption of ions by plants play an important rôle in the effect of the materials used. Ions in certain combinations may be innocuous, while in other combinations they may be quite toxic, due to strong absorption by plants or by the soil, or to disappearance of the companion ion through leaching, or in some other way.

Garjeanne (3) has pointed out that some bryophytes prefer nitrogen as NO_3 while others prefer it is NH_4. Richards (4) has called attention to the fact that "mosses in general strongly avoid salt water. None live in the sea and few can be called true halophytes". These ecological facts may contribute ultimately to an explanation of results reported in this paper.

SUMMARY

The toxicity of 17 chemical compounds, including several common nitrogen and potassium fertilizers and sodium salts, to haircap moss (*Polytrichum commune* L) was studied by field tests. This species of moss is common in New England upland pastures, and is one of the last species to appear in the natural succession of plants on soils of depleted fertility.

It was found that the toxicity of the materials used varied with their ionic combinations. The ions were toxic in the following order: Cations, Na $>$ K $>$ Ca $>$ NH_4: anions, NO_3 $>$ Cl $>$ SO_4 $>$ CO_3.

No correlation was found to exist between the eradicating power of the materials used and the soil reaction induced by them.

The explanation of the effect of the different materials probably lies in the physiological requirements of the moss. Selective absorption by growing plants, fixation by the soil colloidal complex, and chemical and biological changes of materials applied probably play an important rôle in the net results produced in the field.

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THE CORRELATION BETWEEN TILLERING AND PRODUCTIVENESS IN SWEET CORN CROSSES[1]

D. F. JONES, W. R. SINGLETON, AND L. C. CURTIS[2]

THE results obtained by removing the tillers from corn plants has been recently reviewed by Dungan[3] to show that in nearly every case the loss of tillers results in a reduction of yield in both field corn and sweet corn. This investigator has also added the further significant proof that the tillers nourish the main stalk when all the leaves are removed from the main stalk but are left on the side branches.

Nearly all varieties of sweet corn tiller more or less abundantly and especially the earlier sorts. The eight-rowed type of flint corn that is so well adapted to a short cool season also has these side branches. In these types of corn selection of suckerless strains has been attempted but has nearly always failed to establish a desirable variety free from tillering.

From all this evidence we might conclude that tillers serve some useful purpose in the development of the corn plant if it were not for the repeated assertions of many corn growers and agronomists that these so-called "suckers" are of no value and take something away from the main stalk that should go into the formation of ears. They even practice and advocate the removal of these parasites! We might disregard the opinion of practical corn growers when we remember the definition of a "practical man as one who continues to practice the errors of his forefathers," but can we so easily disregard the opinion of agronomists who have been trained in the methods of science, that is, to seek for facts without regard to logical appearances or preconceived theories?

The variety of sweet corn commonly grown in Connecticut for market purposes is Whipple's Yellow. It originated in Connecticut and is characterized by the production of large ears ripening early. No other varieties in this section will produce such large ears in as short a time. The plants are medium in height. The ears are set low on the stalks and there are from one to three or more tillers on nearly every plant. These side branches vary in size from a few inches to the height of the main stalk. Under favorable growing conditions the larger of these tillers produce ears, but these are seldom marketable.

The tillers were removed from this variety by cutting as soon as they were well started, when the main stalk was about 2 feet high. Compared with the untreated plants in alternating rows there was a reduction of 18.9% in total weight of dry ears, 8.2% in number of ears, and 11.6% in average weight of individual ears in a 1-year test. The odds are 10,000:1 that these results are significant. This is a clear indication that tillers are a decided advantage to this variety of sweet corn.

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[1]Contribution from the Department of Genetics, Connecticut Agricultural Experiment Station, New Haven, Conn. Received for publication December 10, 1934.

[2]Geneticist, assistant Geneticist, and assistant in Genetics, respectively.

[3]DUNGAN, GEORGE H., An indication that corn tillers may nourish the main stalk under some conditions. Jour. Amer. Soc. Agron., 23: 662–670. 1931.

We have recently completed a comparison of a number of first generation crosses of inbred strains obtained from the Whipple variety by self-fertilization for four or more generations. These combinations were made by selecting 6 of the best inbreds out of about 100, basing the selection on stalk growth, production of ears, and ear type. These six inbreds were crossed on each other and on all of the other inbreds after discarding the weakest. These crosses were tested 3 years. After the first trial the poorer crosses were dropped out and new combinations were made between inbreds that appeared to be promising. From 56 to 295 different combinations were grown over a period of 3 years in which a record was made of the number of tillers per plant and compared with the total weight of ears, the weight of marketable ears, and the number of marketable ears. At the time the selection of the inbreds and their various combinations was made no consideration was given to the presence or absence of tillers. Many inbred strains make few or no tillers, although crosses from them were well tillered due to the increase in vegetative vigor.

In making the correlations shown in Table 1, the average number of tillers per plant was used. This is obviously not the best measure of the effect of tillering since the total leaf area is probably a more important consideration. Plants with three or four small tillers might not have as much leaf area as other plants with one large tiller. The various crosses were grown in equal sized plats in fields that were fairly uniform in fertility. There was some variation in the number of plants per row and this undoubtedly had a variable effect on the number of tillers. To guard against an undue influence from this environmental factor, the correlations were made between the average number of tillers per plant and the weight and number of ears per plat. A failure to secure a perfect stand would tend to increase the number of tillers per plant but would not increase the number or weight of ears per plat. On the other hand, these figures would be reduced somewhat. The correlations obtained are therefore probably lower than the actual correlations.

Any positive correlation due to an environmental effect on tillering and on yield would be a further indication of the value of tillers, but this obscures the inherited tendency that was specifically studied. Yield records are based on mature, air-dry ears with the husks removed.

It will be noted in Table 1 that there is a positive and significant correlation between the number of tillers and the total weight of ears in 1929 and 1931. None of the correlations for 1930 is significant. There is a significant positive correlation between the number of tillers and the weight of marketable ears in 1929. No figures are available for 1931. There is no significant correlation with the number of marketable ears in any year.

The positive correlations are additional proof that tillers not only are not detrimental, but, on the other hand, are distinctly useful in this type of early maturing sweet corn.

In 1931, correlations were calculated separately for the crosses with one inbred strain in common. The results are shown in Table 2. Clearly some inbreds have the ability to make their tillers more useful

TABLE 1.—*Correlation between average number of tillers per plant and production in crosses of inbred strains of Whipple's Yellow sweet corn.*

	1929	1930	1931
Total weight of ears per plat	+.20±.04	+.11±.09	+.31±.06
Weight of marketable ears per plat	+.17±.04	+.18±.09	———
No. of marketable ears per plat	+.10±.04	+.02±.09	—.01±.06

to their hybrid offspring than do others. Furthermore, those inbreds that show a high correlation in the crosses derived from them also impart high yielding ability, as shown in Table 3. Strains 474–39, 474–82, and 474–76 gave the highest yields when crossed. They are not only notable in yield but also in number, size, and attractiveness of the ears. Of these strains, 474–82 and 474–76 failed to show significant correlations between tillering and yield. This seems to be due to the fact that all of the crosses were uniform in tillering and yielding ability. The standard deviations for tillering and weight of ears are low for the series of crosses in which 474–82 and 474–76 were used as one parent.

TABLE 2.—*Correlation between the number of tillers and the number and weight of ears in a series of first generation hybrids of Whipple's Yellow sweet corn, each having one inbred in common.*

Inbred parent	Number of marketable ears and number of tillers	Weight of ears and number of tillers
474–2	+.35±.09	+.73±.09
474–39	+.32±.09	+.38±.09
474–55	—.21±.11	—.04±.14
474–76	+.29±.09	+.38±.13
474–82	+.02±.01	+.06±.02

TABLE 3.—*The effect of one inbred parent on the number of tillers and the number and weight of marketable ears in a series of first generation crosses of Whipple's Yellow sweet corn.*

Inbred parent	Tillers, No. per plat	Ears, No. per plat	Weight of ears, lbs. per plat
474–82	38.3±1.0	28.5±.6	8.2±.1
482–5	37.3±1.0	30.8±.8	7.8±.2
474–39	34.8±1.1	28.2±.4	8.7±.1
474–2	27.6±1.2	27.8±.5	7.9±.1
482–2	26.7±3.3	25.1±.4	7.8±.2
474–55	23.7±1.1	26.2±.6	7.2±.2
474–76	21.0± .9	29.7±.6	8.2±.1

The crosses with 474–76 average the lowest in number of tillers and yet are second both in number of ears and in weight of ears. This seems to be an exception to the rule that tillering is advantageous, but it should be remembered that the number of tillers is not the important consideration. It is the leaf area on the tillers that aids production. Here we may have a case where the plants produce a few

large tillers. No record was made of this point. It was noted that the crosses with 474–76 were not as early in ripening as most of the other crosses.

If a corn plant has a long growing season, it can produce enough foliage on the main stalk to ripen a large ear, but in short-season varieties the plant can make a larger amount of foliage in the same time by tillering than it can without this aid to increased production.

All of the evidence at hand bears out the contention that tillers are beneficial to the corn plant and are particularly important for market garden types of sweet corn where early production of large ears is a prime consideration.

FIFTEEN YEARS OF SELECTION IN SIX VARIETIES OF BARLEY[1]

MERRITT N. POPE[2]

INTERNODE length of spike is a quantitative character showing considerable variation in a pure line, not only from year to year but also in the populations grown from a single spike and even in the spikes from a single plant. It would seem that such a variable character which is easily measured, would be particularly favorable for testing the validity of the pure-line theory. Fifteen years ago Hayes and Harlan[3] had finished their density studies on barley, and, as their material was available, this experiment was begun to see whether the spike internode length of these barleys could be altered by selection.

METHODS AND MATERIALS

The following varieties were available from the work of Hayes and Harlan: Svanhals, two-rowed, dense, white, hulled; Hanna, two-rowed, lax, white, hulled; Jet, two-rowed, medium dense, black, hull-less; Deficiens, deficient, lax, white, hulled; and Manchuria, six-rowed, medium dense, white, hulled. In addition, a head selection of Hannchen, which is a two-rowed, medium dense, white, hulled sort, was added to the list. Of the varieties used, only Svanhals is known to be of hybrid origin. It was developed at Svalöf, Sweden, from a cross of a common two-rowed sort (probably a Chevalier) and Imperial, which is dense and two-rowed. From this hybrid came the variable variety Diamond. Further selection in Diamond produced the quite different varieties Svanhals and Primus. As Svanhals was first imported into this country in 1901, the original cross must have been made a number of years previous to that time. This variety has shown a marked tendency in certain years toward a branching spike with attendant irregularities in internode length. All the remaining varieties are from single spikes of pedigreed sorts in the origin of which no hybridization is known to have played a part.

Individual spikes from the 1917 plantings were selected showing extreme variations from the mean of the 1916 parental populations on the basis of data obtained in the density studies of Hayes and Harlan. From the progenies of these spikes in 1918 spikes were taken which showed extreme variation in the same directions as those of the parent spikes. No density seedings were made in 1919, but the selections from the 1918 crop, together with the pure line Hannchen, were sown in 1920 under irrigation at Aberdeen, Idaho, where the material has since been grown. Seeds from a single spike were spaced in the row and a single representative spike was harvested from each plant for density measurement.

Beginning with 1922, two spikes each of five families selected for long inter-

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[1]These studies were made in connection with cereal experiments conducted cooperatively at Aberdeen, Idaho, by the Idaho Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication December 18, 1934.

[2]Agronomist, Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. The writer wishes to express his appreciation to Miss Lucille Reinbach, Junior Statistician, Division of Cereal Crops and Diseases, for aid in determining and checking some 1,800 means, and to C. G. Colcord, Scientific Aid, Division of Cereal Crops and Diseases, for computing the regressions.

[3]HAYES, H. K., and HARLAN, H. V. The inheritance of the length of internode in the rachis of the barley spike. U. S. D. A. Bul. 869. 1920.

node length and of five families showing short internode length were grown each year in head rows. Densities were determined upon each spike in the head-row population and the extreme variations in the desired direction preserved. The means were then figured and the head row from each pair of "sib" spikes showing less extreme measurements was discarded. From the remaining row the two spikes the measurements of which were most extreme were chosen for sowing the following year. In this way two selections were effected each year, one within the family represented by two head rows and the other within the spike population of the head row selected from the previous year's crop. Thus opportunity was given for cumulative effect of selection toward greater density in five families and toward less density in five families in each of the six varieties.

So far as practicable, all density measurements on the spikes were made on the 10 internodes between nodes 7 and 17. This distance was shown by Hayes and Harlan to have less variability than that in any other part of the spike. Determinations were made in the beginning by direct comparison with a celluloid or steel metric measuring rule, but later the distance was obtained with sharp-pointed dividers and the spread measured in millimeters upon a steel rule.

The experiment was concluded with the 1932 crop for all varieties except Hanna. The measured difference between lax and dense populations was greater in that year than it had been in that variety heretofore. Then, too, many of the spikes had showed, beginning in the 1925 crop, a tendency (evidently a mutation) toward opposite nodes. This made accurate density measurements difficult. For these reasons Hanna was again grown in 1933, when, instead of harvesting but one spike per plant, all were taken. In measuring, all abnormal spikes were discarded, and from the remainder a random sample was taken to represent the plant.

No precautions were taken to prevent cross pollination, since the amount of natural crossing in barley is very low.[4] The varieties used are so distinct that hybrids are easily recognized. Five such hybrid spikes were noted in the density rows during the whole period, four occurring in Jet and one in Svanhals. It is thought that the possible effects of cross pollination are negligible.

In order to determine whether there is a consistent trend over the period, the regressions of the differences between internode length of lax and dense selections were calculated yearly. The values of "t" were then computed and the values of "P" obtained from Fisher's table of "t".[5]

EXPERIMENTAL RESULTS

For each year in each variety the mean internode lengths were found for the 10 strains of lax and for the 10 strains of dense selections. The variation in these lengths from year to year is much greater in all varieties, excluding Deficiens, than in any year between lax and dense selections of the same variety. In Deficiens, Hayes and Harlan noted an evident mutation in density appearing in 1918 and shown graphically in the bar graph in Fig. 1.

[4]STEVENSON, F. J. Natural crossing in barley. Jour. Amer. Soc. Agron., 20: 1193–1196. 1928.

ROBERTSON, D. W., and DEMING, G. W. Natural crossing in barley at Fort Collins, Colorado. Jour. Amer. Soc. Agron., 23: 402–406. 1931.

[5]FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 4., 1932. (Table IV, page 151.)

Particularly noticeable are the minus differences which occur in the data of all varieties excepting Deficiens. For example, the second largest difference between the means of lax and dense selections occurred in Svanhals in 1925. This had a minus value and amounted to 4.3% of the average of the 20 strains studied. In other words, the five families of Svanhals selected for eight generations for long internodes actually possessed shorter internodes than did the five families selected for short internodes. In Hanna a minus difference occurs in 6 out of the 16 years of selection.

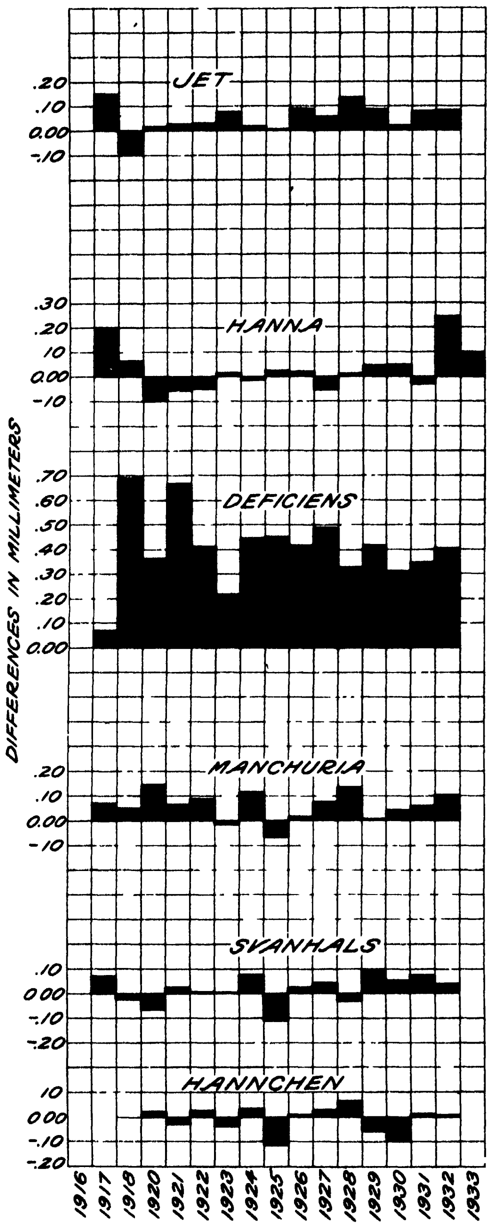

FIG. 1.—Yearly differences in spike internode length between means of lax and dense strains of six varieties of barley.

In Table 1 is shown for each variety, the selection period, the regression coefficient, and its "P" value. "P" values of 0.05 and less are considered statistically significant and are the basis for stating that the amount of variation which gave rise to them could be expected to occur not more than five times in a hundred due to chance alone; consequently, the variation that did occur is attributed to some inherent property of the material under discussion. In no case does "P" have a significant value.

In order to determine whether selection had been effective in any one strain of a variety, the internode lengths of the densest and laxest strains in the last year grown were taken and the an-

TABLE 1.—*The values of "P" found in comparing the means of spike internode lengths in lax and dense selections of each of six varieties of barley.*

	Jet	Hanna	Deficiens	Manchuria	Svanhals	Hannchen
Number of years selected	15	16	15	15	15	13
Coefficient of regression	$.0045 \pm .0031$	$.0045 \pm .0044$	$.0067 \pm .0099$	$.0007 \pm .0032$	$.0037 \pm .0029$	$-.0011 \pm .0036$
Value of "P"	0.171	0.323	0.509	0.826	0.221	0.760

TABLE 2.—*The values of "P" found in comparing the spike internode lengths in the strains found most lax and most dense the last year grown in each of six varieties of barley.*

	Jet	Hanna	Deficiens	Manchuria	Svanhals	Hannchen
Number of years selected	14	16	15	15	15	13
Coefficient of regression	$.0117 \pm .0072$	$.0206 \pm .0072$	$.0256 \pm .0113$	$.0119 \pm .0081$	$.0224 \pm .0047$	$.0003 \pm .0054$
Value of "P"	0.134	0.012	0.042	0.171	0.0001	0.953
Number of years selected	—	last 11	last 13	—	last 11	—
Coefficient of regression	—	$.0131 \pm .0133$	$.0053 \pm .0108$	—	$.0140 \pm .0065$	—
Value of "P"	—	0.351	0.635	—	0.061	—

cestry of each traced back to the original population. The values of the differences between these ancestral internode lengths are plotted on the bar graph in Fig. 2. As before, regressions were calculated and value of "P" found. As will be seen (Table 2), the three varieties Jet, Manchuria, and Hannchen show no significant trend. Hanna, for the total period, does show a significant value for "P". However, when the years 1916 to 1921 are excluded, the variation in the differences in the latter portion of the period indicates no effect of selection.

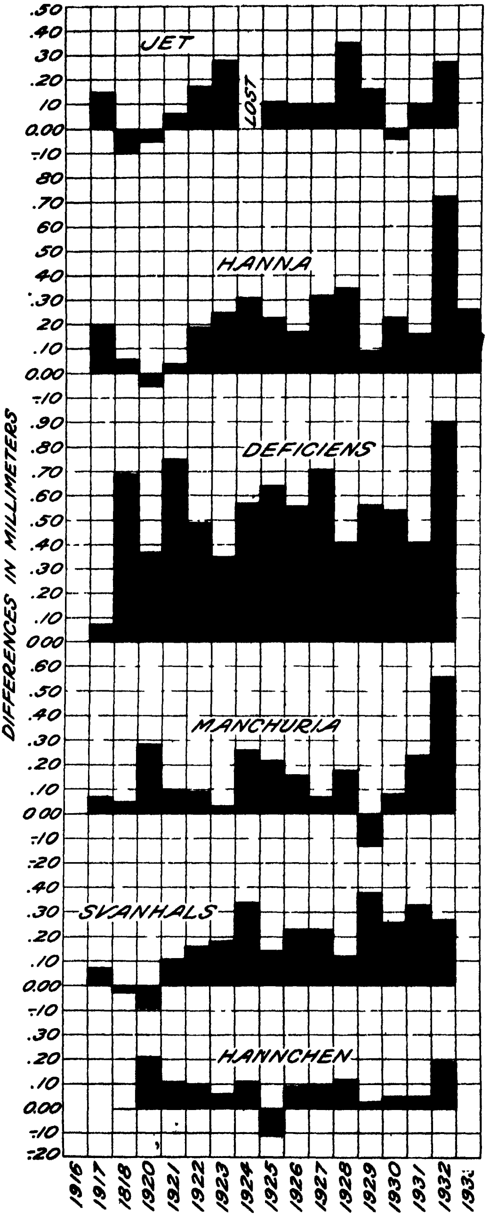

FIG. 2.—Yearly differences in spike internode length in six varieties of barley between the strains found most lax and most dense in the last year grown.

As has been noted, a mutation for density appeared in Deficiens in 1918. Consequently, there is a significant value for "P" for the whole period, the complexion of which changes completely when the years 1916 to 1917 are omitted.

The remaining variety, Svanhals, has an extremely low "P" value, the trend toward a progressively increasing difference between the laxest and densest strains being evident in the bar graph (Fig. 2). However, the data for the last 11 years of the period bring this variety also out of the significant class.

DISCUSSION

In no one of the six varieties used was there a significant trend between the means of the lax selections as compared with the means

of the dense selections. Only when a method was used by which mutations are more easily detected are significant differences found. This method consists of selecting in each variety the strains most divergent for internode length in the last year grown and comparing the ancestral measurements of each year (Fig. 2).

In Jet, Manchuria, and Hannchen neither questions of impurity nor irregularity of behavior during the period have militated against the assumption that they are pure lines. Here the "P" values of the differences both between the means and between the strains found to be most lax and most dense in the last year grown are not statistically significant. In other words, selection has not been effective in producing permanent change in internode length.

In the variety Hanna, the "P" value of the differences between the means of lax and dense strains is 0.323, which is not significant. When the two strains which showed the greatest differences in 1933 were compared, the "P" value is 0.012, which is significant, but, since the "t" test for the last 11 years gives a "P" value altogether too high (seven times) to be significant, there is a strong suspicion that a small mutation for internode length appeared in 1922. Fig. 2 illustrates the lack of trend beginning with this date.

In Deficiens, the differences have been consistently plus throughout the period in both methods of treatment. The mutation for density appearing in 1918 is graphically shown in Figs. 1 and 2. At this point the variety became two pure lines each of which has for 13 years bred true for density, subject only to seasonal variations.

Johannsen[6] defines a pure line as "the descendants from one single homozygotic organism exclusively propagating by self fertilization " This condition can be attained in a plant of heterozygous factorial composition only as a result of self-fertilization continued until all heterozygosity has been eliminated. From the standpoint of practical plant breeding this condition is met in a very few generations of self-fertilization. However, there is always the possibility of the presence of a heterozygous gene in some individual of any later generation. We can never, then, be sure that a variety is a pure line, however long it has been self-fertilized, if it was originally of hybrid origin. Since in Svanhals there is a significantly increasing divergence between its laxest and densest strains (Fig. 2), it is suspected that, due to its hybrid origin, the spike used as the foundation of this line was itself heterozygous for density. Furthermore, its strains have not always acted normally in other particulars, notably in the tendency toward branching and irregular internode length. These facts invalidate the evidence that selection alone was effective in this variety. Since the "P" value for the last 12 years is not significant, it is suggested that purification of this heterozygous condition for internode length occurred in 1921 in one of the two strains compared.

[6]JOHANNSEN, W. The genotype conception of heredity. Amer. Nat., 45 : 135. 1911.

SUMMARY AND CONCLUSIONS

No change in spike internode length of barley is evident in any of six varieties after 15 years of selection when the mean of the lax strains and the mean of the dense strains are compared.

When the strains most divergent for spike internode length in the last year grown are compared, three varieties, Jet, Manchuria, and Hannchen, show no significant trend.

A suspected mutation in density appeared in 1922 in Hanna. No significant trend is evident in 11 years of selection following that date.

A density mutation appeared in 1918 in Deficiens and was effective in producing a permanent difference in internode length.

A "progeny drift (genorhep)" has been recognized only in the case of Svanhals, a barley of hybrid origin.

In a total of approximately 35,000 plants studied there have occurred one mutation for internode length in Deficiens, one for irregularly spaced nodes in Hanna, and a suspected one for internode length in Hanna.

INHERITANCE OF RYE CROSSABILITY IN WHEAT HYBRIDS[1]

J. W. TAYLOR AND K. S. QUISENBERRY[2]

THE possibility of obtaining desirable economic varieties of plants from hybridizing distantly related species or genera continues to be of considerable interest. The results so far obtained have been discouraging, as incompatibility or sterility is found to exist at one or more of the vital phases necessary to begin or continue the work. This is especially true in hybridizing wheat and rye. Here, owing to the almost total sterility of the F_1 plants, very large F_1 generations are necessary. Unless wheats are used that will cross rather easily with rye, it is difficult to obtain a large F_1 generation. The problem may become still further complicated by the fact that the wheat varieties that cross readily with rye do not carry the desired agronomic characters. Any procedure that will further the success of transferring desirable rye characters, especially winterhardiness, to wheat is of considerable value.

REVIEW OF LITERATURE

Wheat varieties differ decidedly in their crossability with rye, as shown by Firbas (2)[3] and Jesenko (3). Firbas obtained no conclusive results on the value of different environmental factors in crossing wheat with rye. No extensive testing of the common American wheats for rye crossability has been made, but so far as known no economic variety is outstanding for this character. Certain Chinese wheats, however, cross readily with rye as shown by Backhouse (1), Thompson (7), and Leighty and Sando (4). The almost total sterility of the F_1 wheat-rye hybrid has been shown by Jesenko (3) and Leighty and Taylor (5).

METHOD AND MATERIALS

The purpose of these experiments was to develop a method whereby large numbers of desired F_1 wheat-rye combinations could be obtained to facilitate breeding for more winterhardy wheats. This was attempted by two methods, as follows:

1. By crossing a variety (Purplestraw) of low crossability with rye (Abruzzes), backcrossing the resulting F_1 with Purplestraw, allowing this wheat-rye wheat type to self, and testing the resultant individuals for inherited crossability.

2. By crossing winterhardy varieties (Minhardi and Minhardi x Minturki, C. I. 8034) of low crossability with a rye crossable wheat (Chinese) (4), which, however, is not winterhardy, and obtaining crossable hardy types of wheat.

The experiments were conducted in the greenhouses and in the field at the Arlington Experiment Farm near Washington, D. C.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication December 19, 1934.

[2]Associate Agronomist and Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 153.

EXPERIMENTAL DATA

TRANSFERRING CROSSABILITY TO WHEAT TYPES BY HYBRIDIZING WHEAT AND RYE

The data in Table 1 show that Purplestraw was low for crossability with rye, as a seed set of only 1.5% was obtained. Five varieties of rye were used in pollinating Purplestraw, but no individuality in crossing was shown by the ryes. When the F_1 of Purplestraw x rye was backcrossed with wheat, there resulted two seeds in some 1,000 pollinations. These two seeds produced plants that dehisced normally and were self-fertile. The progeny of one of these plants, designated in Table 1 as wheat-rye-wheat, consisted of 10 individuals, all of which were pollinated with rye. Eight of the 10 plants showed crossability, and from pollinating the 10 plants a 19% seed set was obtained. Further pollinating of the wheat-rye-wheat line with rye showed crossability of over 30%.

TABLE 1.—*Rye crossability of certain wheat varieties and hybrids.*

Variety or hybrid	C. I. No.	No. of flowers pollinated	No. of seed set	Seed set %
Purplestraw	1915	1,497	23	1.5
Minhardi	5149	84	1	1.2
Minhardi x Minturki	8034	42	0	0
Chinese	6223	548	378	69.0
(Minhardi-Minturki) x Chinese (F_1)	—	238	3	1.3
Minhardi x Chinese (F_1)	—	218	0	0
Wheat-rye-wheat (F_2)	—	448	85	19.0
Wheat-rye-wheat (F_3)	—	835	276	33.1
Wheat-rye-wheat (F_4)	—	48	17	35.4

The wheat-rye-wheat type is in all morphological appearances true wheat resembling closely the Purplestraw parent. However, in addition to its crossability with rye, one additional character of genetic importance was manifested. Of the 20 F_1 hybrids of wheat-rye-wheat X Abruzzes rye that matured, two dehisced some of their anthers and one gave a single selfed seed. From this seed originated a so-called nonsegregating line intermediate between wheat and rye. So far as is known, no certain instance of natural anther dehiscence or of self-fertility in an F_1 wheat-rye hybrid has been reported. Love and Craig (6) obtained one seed under open-pollinated conditions, which, they believe, may have been a selfed seed.

INHERITANCE OF CROSSABILITY IN WHEAT HYBRIDS

The winterhardy varieties Minhardi and Minhardi-Minturki, C. I. 8034, showed low crossability with Dakold rye (Table 1). The tender Chinese variety, however, under similar conditions gave a 69% seed set when pollinated with Dakold. The F_1 hybrids of Minhardi X Chinese showed no seed set and (Minhardi-Minturki) X Chinese, only a 1.3% seed set when crossed with rye.

As may be seen from the data in Table 2, segregation for crossability occurred in the F_2 generation. Eighty-one individual plants of the Minhardi X Chinese cross were pollinated with rye, 48 gave no seed, 19 gave less than 10% with an average set of 3.8, and 14 gave a seed set of 10% or more with an average of 27.3. In Table 2 these are listed in arbitrary classes of crossability as none, light, and heavy.

TABLE 2.—*Rye (Dakold) crossability of F_2 plants of Minhardi X Chinese and (Minhardi-Minturki, C. I. 8034) X Chinese grouped into arbitrary classes of crossability.*

No. of plants tested	Arbitrary class for crossability	No. of flowers pollinated	No. of seeds set	Crossability with rye %
		Minhardi X Chinese		
48	None	1,880	0	0
19	Light	878	33	3.8
14	Heavy	550	150	27.3
Total 81	—	—	—	—
		(Minhardi-Minturki, C. I. 8034) X Chinese		
59	None	2,040	0	0
17	Light	628	27	4.3
12	Heavy	481	165	34.3
Total 88	—	—	—	—

The F_2 of Minhardi-Minturki X Chinese was very similar to the preceding cross as may be seen from Table 2. In this case of 88 individuals, 59 plants set no seed, 17 showed a light set, with an average of 4.3%, and 12 gave a set of 10% or over with an average of 34.3%.

Inasmuch as crossability behaved as a recessive character, and to hold to the purpose of the experiment, only those F_2 plants showing crossability and vigor were continued in the F_3. The results of testing individuals in the F_3 generation are given in Table 3. Eight F_3 lines of Minhardi X Chinese, involving 47 plants, and 10 lines of (Minhardi-Minturki, C. I. 8034) X Chinese, involving 84 individuals, were crossed with rye. The lowest crossability in any F_3 line was approximately 12% and the highest over 80%. Where the crossability was as low as 12%, several pollinations gave no seed, but this is attributed to pollinating conditions rather than lack of crossability.

WINTERHARDINESS OF F_4 LINES CROSSABLE WITH RYE

A preliminary field test for winterhardiness of F_4 lines of Minhardi X Chinese and (Minhardi-Minturki) X Chinese showing rye crossability was made in the nursery during the crop year 1933–34. On two dates in February the mercury dropped to —7° F. As may be seen in Table 4, the Chinese parent had a very poor survival, whereas Minhardi and Minhardi-Minturki, C. I. 8034, had good and excellent survivals, respectively. The F_4 lines ranged from very poor to excellent in survival. Some lines apparently were equal to the winterhardy parent in this test and nearly all were better than the Chinese

parent. From this preliminary test of winterhardiness it is indicated that a combination of the two characters, i. e., crossability with rye and winterhardiness, has been obtained.

TABLE 3.—*Rye (Dakold) crossability of F_3 lines of Minhardi X Chinese and (Minhardi-Minturki, C. I. 8034)X Chinese.*

Line number	No. of plants	No. of flowers pollinated	No. of seeds set	Crossability with rye, %
		Minhardi X Chinese		
51	6	117	34	29.1
52	8	137	55	40.1
53	9	167	74	44.3
54	10	190	22	11.6
55	7	124	27	21.8
66	3	26	13	50.0
67	2	38	9	23.7
69	2	29	25	86.2
		(Minhardi-Minturki, C. I. 8034) X Chinese		
56	10	186	45	24.2
57	8	147	18	12.2
58	10	201	114	56.7
59	10	186	84	45.2
60	9	176	59	33.5
61	8	154	39	25.3
62	9	168	51	30.4
63	10	197	77	39.1
64	8	159	57	35.8
65	2	33	27	81.8

TABLE 4.—*Comparative winter survival of F_4 rye crossable lines of Minhardi X Chinese, (Minhardi-Minturki) X Chinese, and parent.*

Variety or hybrid	Number of F_4 lines or parents surviving				
	Very poor	Poor	Fair	Good	Excel-lent
Minhardi X Chinese	2	10	16	10	2
(Minhardi-Minturki, C. I. 8034) X Chinese	4	14	16	26	1
Minhardi	—	—	—	1	-
Minhardi-Minturki, C. I. 8034	—	—	—	—	1
Chinese	1	—	—	—	-

DISCUSSION

Crossability of wheat with rye is a heritable character that can be transferred to wheat segregates by hybridizing wheat and rye. By this method a strain similar to wheat was produced, which, in addition to its crossability with rye, gave two F_1 hybrids showing some anther dehiscence and one of which produced a selfed seed. Pollen development to the extent of causing natural dehiscence of anthers and self-fertility, under controlled conditions, has never before been observed. However, it is possible that the slight fertility reported by Love and

Craig (6) in their F_1 wheat-rye hybrid may have been true self-fertility and not the result of backcrossing with wheat.

Transferring the rye crossability present in known varieties of wheat to more desirable wheat segregates by intervarietal crossing was readily accomplished. The results confirm the preliminary report of Backhouse (1), who pollinated 17 F_2 plants of a crossable X non-crossable wheat and found four that set seed. Although in both cases the numbers are small, crossability appears to be controlled by a main recessive genetic factor. It is possible, however, that minor modifying factors may also be present.

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POLE BEANS VS. SOYBEANS AS A COMPANION CROP WITH CORN FOR SILAGE[1]

R. G. WIGGANS[2]

WITH the increased interest, particularly in the northeastern United States, in the combination of a legume with corn for silage purposes has come the question, many times repeated, "Why not grow pole beans with corn for silage?" This question was postulated on the assumption that production would be equally good and some of the difficulties of harvest would be eliminated due to the ability of the pole bean to use the corn plant as a support and to remain with the corn plant at harvest time without loss of a significant amount of the legume.

The purpose of this brief report is to present data obtained from experiments planned to give information on this problem.

METHOD

In 1933, a pole bean, Kentucky Wonder, was included in the regular experiment where soybean varieties were being tested with corn for silage. The test was twice repeated in 1934, one series only receiving inoculation.

In order to be able to compare the yield of the combinations with corn alone, a given variety of corn was grown at a uniform rate over a considerable area with soybeans or pole beans planted with the corn in three out of four rows. The fourth row served as a check and also gave a measure of the ability of the land to produce corn alone. The rate of corn planting was the optimum for corn silage under the conditions of the experiment, namely, 9 inches apart in rows 3 feet apart. Soybeans or pole beans when added were planted at the rate sufficient to give three legume plants to one of corn. Almost a perfect stand of corn was obtained by accurate spacing at planting time and dropping two or three kernels where one plant was desired, followed by subsequent thinning. The legumes were not thinned but a stand approaching closely to that desired was secured by planting an excess of 10% germinable seed over the amount necessary for the desired stand provided all germinable seed produced plants. The individual rows were 50 feet long and were repeated eight times. Two standard silage corn varieties for the region were used. In order to show the contrast between pole beans and soybeans, two varieties only of soybeans were taken from the several in the test.

The corns and the legumes were harvested separately and weighed immediately. Shrinkage samples were taken on three of the eight series (approximately 40 pounds of corn and the entire harvest of soybeans) and later kiln dried in order to determine the dry matter percentage in the green material and finally by taking the average of the three shrinkage samples to get the dry weight production of the corn and of the legume separately. The percentage dry shelled grain in the corn was also determined in the shrinkage samples.

RESULTS

The fact that a legume grown with corn for whatever purpose reduces the yield of corn, whether measured in total dry matter pro-

[1]Paper No. 207, Department of Plant Breeding, Cornell University, Ithaca, New York. Received for publication December 20, 1934.

[2]Professor of Plant Breeding.

duction or yield of grain, has long been established and needs no further proof. The total production of dry matter, however, is a controversial point and needs further evidence. The data given in Tables 1 and 2 are presented as evidence on this problem. Kentucky Wonder pole beans when grown with West Branch corn caused an average loss in dry weight production of the corn of 2,363 pounds per acre, or 28%. When grown with Cornell No. 11 corn, the loss was 2,107 pounds per acre, or 27.3%. Corresponding losses in grain production were 753 pounds, or 33.5%, in West Branch and 992 pounds, or 33.0%, in Cornell No. 11. The losses in dry weight production were not made up by the yield of the bean which on the average was 745 pounds of dry matter when grown with West Branch and 752 pounds with Cornell No. 11. The differences between the losses of corn and the production of the legume showed an average loss of 1,618 pounds, or 19.8%, in total dry matter when Kentucky Wonder pole beans and West Branch corn were grown together, while a similar loss of 1,351 pounds, or 18.7%, occurred when Cornell No. 11 was used. These differences are large, consistent, and statistically significant, giving satisfactory proof of the inadvisability of growing the two together for silage purposes under conditions similar to those of the experiment.

The duplicate series of plats as grown in 1934 showed no statistical difference as a result of inoculation. This was due to the fact that the plants of both series showed approximately equal inoculation, thus giving satisfactory proof of the presence in the soil of the proper organism for bean inoculation. The final results of the 1933 test had aroused the suspicion that the pole beans had not been inoculated and that the small yield of the legume and the depressing effect on the corn might be explained on that basis. No observations were made on the amount of inoculation in 1933. It had been assumed that the proper organism for inoculation was present, an assumption proved to be correct by the 1934 results.

In order to show the effect of soybeans on corn and the total dry matter production, data similar to that given for Kentucky Wonder pole beans is given for Wilson and Peking soybean varieties, the one to represent the indeterminate and the other the determinate habit of growth. (Any two of several other varieties might have been chosen with similar results.) Here, again, decreases in the total dry matter in West Branch corn were 12.4% and 14.5%, while grain showed decreases of 18.9% and 20.0%. The soybean varieties gave yields of dry matter equivalent to 17.8% and 20.3% of corn alone. The losses in total dry matter production in corn were more than made up by the yields of the soybeans. Actual increases of 5.3% and 6.8% occurred in total dry matter production. Cornell No. 11 corn when grown with the same varieties of soybeans showed corresponding increases of 9.2% and 7.2%.

The contrasting behaviors of pole beans and soybeans, when grown with corn for silage, resulted in approximately twice as much decrease in the corn yield with pole beans as with soybeans and a production of approximately half as much dry matter. This caused an average loss of 19% in total dry matter in one case and a 7% gain

TABLE 1.—*West Branch corn in combination with pole beans and soybeans for silage.*

Legume	Variation from theoretical check in dry weight*						Gain or loss of combination compared with corn alone	
	Total corn		Corn grain		Legume			
	Lbs. per acre	Percentage	Lbs. per acre	Percentage	Lbs. per acre	Percentage	Lbs. per acre	Percentage
			1933					
Ky. Wonder pole bean	—2,009	—23.3	—481	—23.7	395	4.6	—1,614±181	—18.7
Wilson soybean	— 899	—10.6	—209	—10.5	1,413	16.7	514±111	6.1
Peking soybean	— 843	—10.3	—206	—10.5	1,562	19.1	719± 64	8.8
			1934					
Ky. Wonder pole bean†	—2,617	—33.8	—906	—44.3	927	12.0	—1,690± 77	—21.8
Ky. Wonder pole bean	—2,462	—31.8	—871	—42.6	912	11.8	—1,550± 99	—20.0
Wilson soybean	—1,112	—14.3	—560	—27.4	1,468	18.9	356±151	4.6
Peking soybean	—1,295	—16.7	—605	—29.6	1,664	21.5	369± 67	4.8
			Average 1933–34					
Ky. Wonder pole bean	—2,363	—28.0	—753	—33.5	745	8.2	—1,618± 96	—19.8
Wilson soybean	—1,005	—12.4	—384	—18.9	1,440	17.8	435± 94	5.3
Peking soybean	—1,069	—14.5	—405	—20.0	1,613	20.3	544± 46	6.8

*Probable errors were calculated for all variations from theoretical checks, but are not included because in no case was the P.E. equivalent to 10% of the difference.
†Inoculated.

TABLE 2.—*Cornell No. 11 corn in combination with pole beans and soybeans for silage.*

Legume	Variation from theoretical check in dry weight*						Gain or loss of combination compared with corn alone	
	Total corn		Corn grain		Legume			
	Lbs. per acre	Percentage	Lbs. per acre	Percentage	Lbs. per acre	Percentage	Lbs. per acre	Percentage
			1933					
Ky. Wonder pole bean	—2,233	—26.3	—1,211	—34.4	302	3.6	—1,921±196	—22.6
Wilson soybean....	—1,342	—15.9	— 884	—25.2	1,613	19.1	272±133	3.2
Peking soybean	—1,449	—17.3	— 920	—26.5	1,653	19.7	204±127	2.4
			1934					
Ky. Wonder pole bean†	—1,890	—26.3	— 826	—29.7	957	13.3	— 936±220	—13.0
Ky. Wonder pole bean.	—2,197	—30.6	— 940	—33.8	1,001	13.9	—1,196±183	—16.6
Wilson soybean...	— 718	—10.0	— 394	—14.2	1,809	25.2	1,091± 94	15.2
Peking soybean	— 945	—13.1	— 477	—17.1	1,807	25.1	862±117	12.0
			Average 1933–34					
Ky. Wonder pole bean	—2,107	—27.3	— 992	—33.0	752	8.6	—1,351±121	—18.7
Wilson soybean....	—1,030	—12.9	— 639	—19.7	1,711	22.1	681± 81	9.2
Peking soybean..........	—1,197	—15.2	— 698	—21.8	1,730	22.4	533± 86	7.2

*Probable errors were calculated for all variations from theoretical checks, but are not included because in no case was the P.E. equivalent to 10% of the difference.

in the other. These extreme differences may be explained at least partially by:

1. The more vigorous growth of pole beans at early stages with an increased shading effect and greater demand for nitrogen and other food nutrients. It was observed that the corn seedlings growing with Kentucky Wonder beans started slower in the spring. This handicap was never overcome.

2. The fact that the Kentucky Wonder pole bean produces a greater shading effect throughout the period of elongation as a result of its twining habit and larger leaves.

3. The fact that twining prevents to a greater or less extent the full expansion of all corn leaves.

4. The pole bean was for the most part mature at harvest time. This condition was partly the result of the early pods remaining on the plants and thus causing physiological maturity at an earlier date than if the pods had been removed, while the soybeans were in an active state of growth throughout the season.

Table 3 is given to show the actual yields of corn when grown alone. By the use of this table with the two preceding ones, the average yield of the combinations may be calculated.

TABLE 3.—*Yield of corn grown alone.*

Year	Corn variety	Dry weight per acre, lbs.	
		Total	Grain
1933	West Branch	8,415±128	1,986±30
	Cornell No. 11	8,448±123	3,506±51
1934	West Branch	7,752± 76	2,046±20
	Cornell No. 11	7,191±100	2,783±39

Although only 2 years' results are available, the extreme differences between the behavior of pole beans and soybeans when grown in combination with corn and the very significant loss in total dry matter when Kentucky Wonder pole beans are used with corn for silage seem to justify the following conclusions for conditions similar to those of New York state:

1. That Kentucky Wonder pole beans cannot be grown to advantage with corn for silage.

2. That the loss in dry weight production of corn in a corn and soybean combination is more than made up by the dry weight production of the soybeans.

NOTE

EFFECT OF OVER-GRAZING ON KENTUCKY BLUEGRASS UNDER CONDITIONS OF EXTREME DROUTH

IN a survey taken in October 1934 by H. D. Hughes, H. L. Eichling, and F. S. Wilkins of Iowa State College in the severe drouth area of southwestern Iowa, it was found that about 90% of the Kentucky bluegrass was killed by the combination of drouth and heat during the summer of 1934. The rainfall was only about 50% of normal during June, July, and August and temperatures were over 100° for 30 days or more during the summer. In most of the pastures of this section 90 to 95% of the Kentucky bluegrass, which comprised nearly all of the cover, was found to be dead. Scattered, small, weakened, live Kentucky bluegrass plants, however, remained.

Throughout the survey, which was made about 3 weeks after fall rains began, it was observed that the pastures which had been the most closely grazed suffered the worst, and three pastures within 2 miles of each other near Clarinda, showing remarkable contrast in condition, gave mute evidence of the disastrous effect of over-grazing. In the most heavily grazed pasture spindly bluegrass plants, 1 to 3 feet apart, were being kept eaten off at ground level by many hogs. Over 99% of the Kentucky bluegrass in this pasture was dead and practically no live cover remained. Across the fence about 75% of the bluegrass had been killed and vegetation consisting of Kentucky bluegrass and foxtail was being given considerable opportunity to develop. This pasture gave the appearance of having been moderately to heavily grazed during the drouth period and before.

Within 2 miles a pasture was found on the same soil type and of similar topography where the turf and cover of Kentucky bluegrass were excellent, with practically no dead plants. The operator stated that this pasture had been grazed moderately to lightly in 1933 and 1934 while he had charge of the farm. He said also that during the drouth period of 1934 the top growth gave every appearance of being dead.

Evidence that over-grazing aggravated effects of drouth and heat and was the indirect cause of the death of about 90 per cent of the Kentucky bluegrass was so convincing that there is little doubt that discontinued or intermittent grazing will be the most effective means of restoring such pastures. Reseeding with legumes, and in some cases grasses as well, and soil treatments will be helpful, but each farm operator even of limited means can give his pasture needed rest by providing small grain and other emergency pastures. The Iowa workers would like to have the ideas of other agronomists concerning this important problem.—F. S. WILKINS, *Iowa State College, Ames, Iowa.*

AGRONOMIC AFFAIRS

NEWS ITEMS

DR. D. F. JONES, head of the Department of Genetics of the Connecticut Agricultural Experiment Station at New Haven and recently elected President of the Genetics Society of America, delivered the Spragg Lectures at Michigan State College. His topics were as follows: "Genes, Present and Missing;" "The Interpretation of Hybrid Vigor;" "The Production of Inbred Strains of Corn;" and "The Testing and Utilization of Inbred Strains of Corn."

A CORRESPONDENT of the U. S. S. R. reports increasing interest in iarovization in the Soviet Union. It is reported that almost universal application of the process is being made to wheat, sugar beets, potatoes, oats, barley, millet, sunflower, lupins, cotton, grasses, and legumes.

NUMBER 10 of the periodical published by the All-Union Institute of Plant Industry of the U. S. S. R., known as "Socialist Plant Industry," contains the following articles: "Soviet Scientific Plant Industry During the Period of Socialist Reconstruction," by N. I. Vavilov; "Soviet Cytology and Plant Industry for the Past Year," G. A. Levitsky; "The Study of Hybridization of Plants," by G. D. Karpachenko; "Soviet Agro-physiology and Its Achievements During Recent Years," by T. A. Krasnosellskaya-Maximova; and others. Number 9 of this periodical contains a complete bibliography of all books and bulletins which appeared in the U. S. S. R. during 1932 on the subject of plant industry. While the periodical is published in Russian, most of the titles have English translations.

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PASTURE AREAS IN THE UNITED STATES[1]

H. N. VINALL[2]

IN the United States there are five fairly definite pasture regions resulting from climatic conditions. Due to the response of various pasture plants to either temperature or rainfall conditions, or both, each region may be appropriately divided into two sections, a northern and a southern.

CHARACTERISTICS OF DIFFERENT PASTURE REGIONS

Since temperatures, rainfall, topography, and soil each have a marked effect on the distribution and character of the flora, these features of the pasture regions outlined above are discussed briefly. Most attention, however, is given to the vegetation which characterizes each region.

TEMPERATURES

Anyone who has given the least consideration to vegetation characteristics knows that climate is the chief factor governing the distribution of plant species over the earth. In the United States, the 60° isotherm marks as closely as any temperature factor available the northern limit of usefulness of southern pasture plants such as the bermuda, carpet, Dallis, and centipede grasses. The exceptions to this general rule are mostly annuals such as the hopclovers, lespedeza, and Sudan grass. North of this line southern perennials are not fully winterhardy and are on the whole less valuable than the northern type of pasture plants. South of this isotherm bluegrass, orchard grass, timothy, redtop, and the clovers, which are at home and provide productive pastures in Region 1 and Sec. 5a, do not thrive because of the long period of high temperatures.

The discussion of the temperature factor relates chiefly to the humid regions (1, 2, and 5a) because in the Great Plains and Intermountain area (Regions 3 and 4) rainfall exerts a greater influence on the vegetation than do temperatures. The line of demarcation between the floristic groups is of course not sharp. The southern type

[1]Contribution from Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. Presented as part of a symposium on "The Relation of Pastures to the Land Utilization Program," at the annual meeting of the Society held in Washington, D. C., November 22, 1935. Received for publication December 10, 1934.

[2]Senior Agronomist.

is found north of isotherm 60° and the northern type south of it. In other words, there is on any of these arbitrary division boundaries an overlapping of the characteristic flora of the adjoining divisions. This is in many cases due to soil differences. On the whole, however, a large proportion of the pasturage in a given region is supplied by the type of vegetation indicated on the map (Fig. 1).

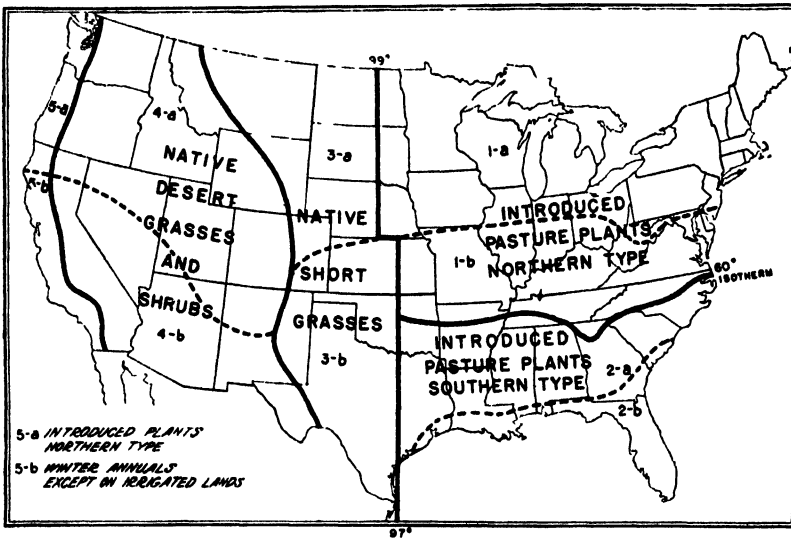

FIG. 1.—The five natural pasture regions as determined by climate are indicated by solid lines. Each of these regions is subdivided by dotted lines into sections *a* and *b*, chiefly because of their temperature relations, except on the Pacific slope where *a* represents the more or less humid northern section and *b* the rather arid southern section. The kinds of pasture plants which provide most of the pasturage in each region are indicated. (From U. S. Dept. of Agriculture, Misc. Pub. No. 194. 1934.)

PRECIPITATION

The available soil moisture as affected by precipitation in the form of rain and snow becomes the controlling factor in respect to the flora west of Regions 1 and 2 (Fig. 2). The western boundary of these regions is a combination of the 99th meridian in the North and the 97th meridian in the South. In proceeding west through the eastern humid area this line marks the approximate western limit where introduced pasture plants are more productive for grazing purposes than native plants. The line separating Regions 1 and 2 from Region 3 veers to the west as it approaches our northern boundary because the total evaporation from a free water surface during the warm seasons, April to September, inclusive, is about 30 inches at the Canadian boundary and over 65 inches at the Mexican boundary line. The effectiveness of the annual rainfall varies with the relation of the rainfall to the evaporation. Thus 20 inches of rainfall in North Dakota will produce crop yields equivalent to a 30 inch rainfall in Texas.[3]

[3]KINCER, J. B. Atlas of American Agriculture. Part II, Sec. A: 48.

This relation of rainfall and evaporation in its effect on crop yields was pointed out first by Briggs and Belz in 1910.[4] Some authorities have attempted to follow soil lines in marking the eastern boundary of the Great Plains, but so far as crop production is concerned rainfall is the limiting factor and is believed to be the most important one in separating the pasture regions

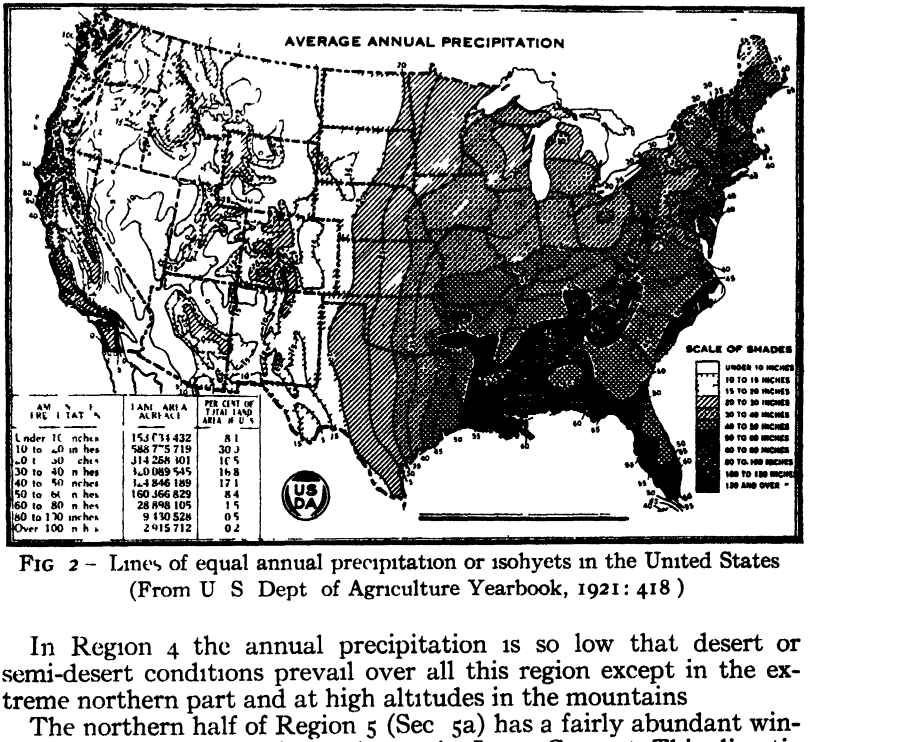

FIG 2 – Lines of equal annual precipitation or isohyets in the United States (From U S Dept of Agriculture Yearbook, 1921: 418)

In Region 4 the annual precipitation is so low that desert or semi-desert conditions prevail over all this region except in the extreme northern part and at high altitudes in the mountains

The northern half of Region 5 (Sec 5a) has a fairly abundant winter rainfall and a mild climate due to the Japan Current This climatic condition results in dense coniferous forests, mostly spruce, and in very productive improved pastures

TOPOGRAPHY

The contour of the United States is broken by three important mountain ranges extending in a general north and south direction from the Canadian boundary line nearly to the southern boundary of the United States. The easternmost is the Appalachian system, the central and highest is the Rocky Mountains and the one near the Pacific Coast is composed of the Sierra Nevada and Cascade ranges. West of the latter ranges, however, are a series of low groups of mountains quite near the ocean which as a whole are referred to as the Coast Range.

[4]BRIGGS, L H., and BELZ. J. O. Dry farming in relation to rainfall and evaporation U. S. Dept. Agr. Bur. Plant Ind. Bul. 188: 21. 1910.

The mountain areas, because they are rather completely forested and composed mostly of rock masses with very little productive soil, are unimportant from a pasture standpoint. In some of the mountain valleys at high altitudes it is possible to establish good improved pastures and in the West cattle and sheep are often moved into the foothills from the low-altitude ranges when the pasturage on the latter proves inadequate.

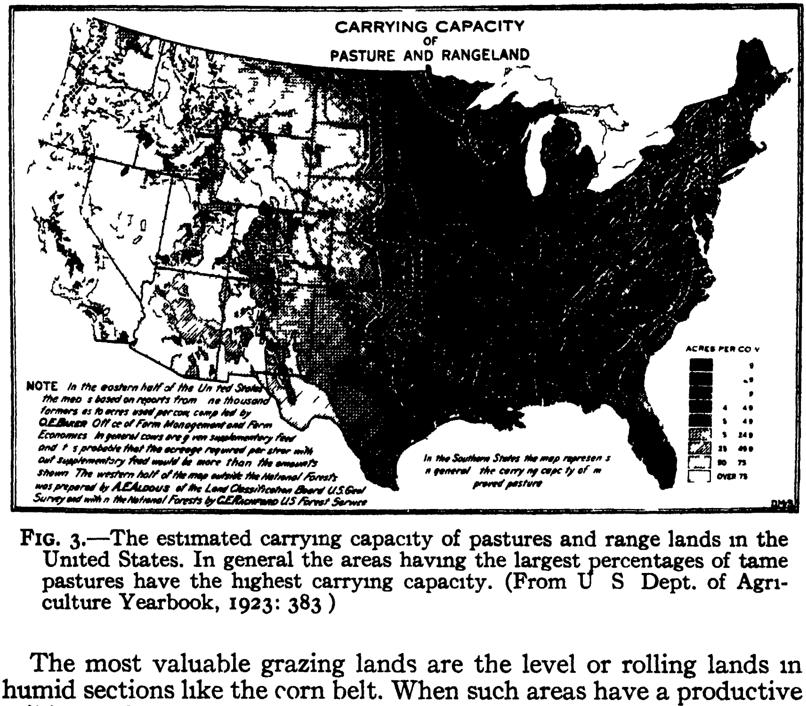

FIG. 3.—The estimated carrying capacity of pastures and range lands in the United States. In general the areas having the largest percentages of tame pastures have the highest carrying capacity. (From U S Dept. of Agriculture Yearbook, 1923: 383)

The most valuable grazing lands are the level or rolling lands in humid sections like the corn belt. When such areas have a productive soil it requires less than 2 acres to support one animal unit during the grazing season The level lands in the Great Plains are also good pasture lands, but are less productive than similar grazing lands in the corn belt because of low rainfall. The low, swampy lands bordering the Atlantic and Pacific oceans and the Gulf of Mexico are occupied generally by tall, coarse grasses and by sedges and rushes Such vegetation is lacking in both palatability and nutritive value, hence its carrying capacity is low. A map of the United States showing the estimated carrying capacity of pastures and range-lands shows clearly where the most productive pastures are found (Fig. 3).

SOIL RELATIONS

Next to climate and topography soil characteristics have the most influence not only on the productiveness, but also on the type of pasture plants which occupy the land. The carrying capacity of pastures indicated in Fig. 3 is, in areas having similar climatic condi-

tions, highest on the notably rich soils of the corn belt. The presence of legumes in pastures also increases their nutritive value and legumes are with few exceptions most abundant on soils of limestone origin. In considering the vegetation found in the various pasture areas, at least the broader phases of soil characteristics should be kept in mind. The main soil groups or provinces of the United States are shown in Fig. 4.

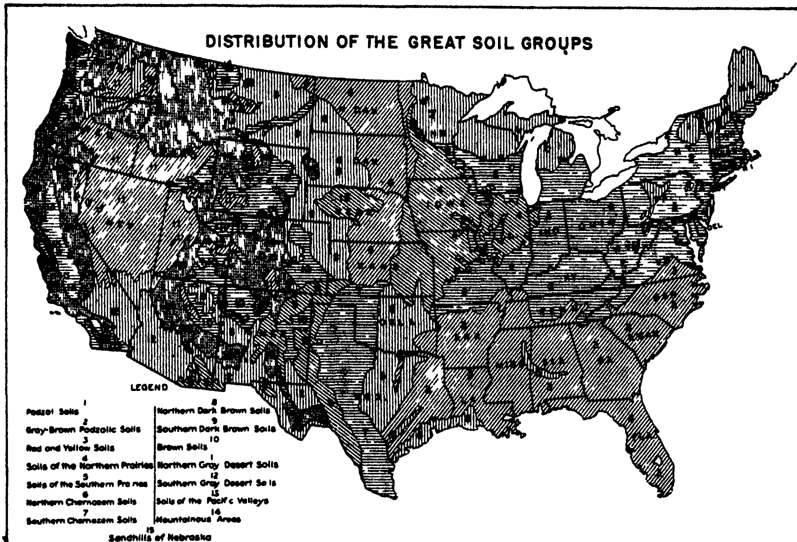

FIG. 4.—This map, prepared by Dr. C. F Marbut, indicates only the major soil differences. In each of these Regions there are areas of varying size which differ in certain essentials. The detailed soil survey maps issued by the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, and by the states show these minor variations.

Leaving out of consideration the mountain areas, the land surface of the United States is divided into seven large soil provinces. In the order of their productiveness, if the influence of climate is ignored, the prairie soils would rank first; the chernozem or black soils, second; the dark-brown soils, third; the gray desert soils, fourth; the gray-brown podzolic soils, fifth; the podzols, sixth; and the red and yellow soils, seventh or lowest in inherent productivity because they are leached more than any other group of soils. The small soil group known as the soils of the Pacific valleys are deep sedimentary soils which are naturally productive, perhaps equalling in this respect the second or third groups indicated above. If only pasture Regions 1 and 2 where the rainfall is normally adequate are considered, the four soil provinces would rank in productiveness as follows: (1) Prairie; (2) gray-brown podzolic, (3) podzols, and (4) red and yellow.

The high ranking of the desert soils may seem unjustified, but their inherent productiveness is demonstrated whenever they are irrigated. Lack of adequate rainfall in the Great Plains also reduces the actual

production of the dark-brown and black or chernozem soils which intrinsically are very little less productive than the Prairie soils.

The effect of the depth of the soil has a considerable influence on the kind of grass and other forms of vegetation which occupy the land. The tall prairie grasses do not succeed where the rainfall is inadequate or the soil structure is such that the roots cannot penetrate to a considerable depth.

VEGETATION

The vegetation most important from a pasture standpoint is the grasses and legumes. In Regions 1, 2, and 5 these are preponderantly introduced species, but even in such cases it is desirable to know what class of native vegetation preceded the introduction of foreign plants.

Region 1.—Almost all of this region was originally hardwood forest and the land had to be cleared of trees before it could be cultivated and seeded to pasture plants. The chief exception to this rule was the tall-grass prairie extending eastward from eastern North and South Dakota, Nebraska, and Kansas through southwest Minnesota, Iowa, and northern Missouri into central Illinois. Big bluestem (*Andropogon furcatus*)[5] generally associated with Indian grass (*Sorghastrum nutans*) was the dominating species on these prairie lands and small areas of this splendid hay and pasture grass are still found, although such reminders of the early days are rare because the prairie soils were productive and more easily prepared than timber lands for growing cultivated crops. In the drier habitats, particularly on the western edge or transition zone of the prairies, the little or bunch bluestem (*A. scoparius*) predominates and often penetrates into the plains or short-grass formation. This dominance of the little over the big bluestem and its penetration into the short-grass formations is especially noticeable in the eastern parts of Nebraska, Kansas, and Oklahoma. Farther north in western Minnesota and the eastern edges of North and South Dakota the prairie formation is largely a combination of needlegrass (*Stipa spartea*) and slender wheatgrass (*Agropyron tenerum*).

Considering Region 1 as a whole, Kentucky bluegrass is by far the most important pasture grass. In mixture with white clover it is nearly always present on productive soils in permanent pastures. Next in importance are Canada bluegrass, redtop and its allies the bent grasses, timothy, orchard grass, brome grass, and the fescues. South of the dotted line in Section 1b, lespedezas, Korean and common, are becoming increasingly abundant in pastures and greatly increase their carrying capacity, especially during the summer months.

In the eastern part of Section 1a the permanent pastures on poor upland soils and where they are neglected and overgrazed are occupied chiefly by sweet vernal grass and poverty grass along with such weeds as ox-eye daisies, goldenrod, dandelion, yarrow, wild carrot, cinquefoil, hawkweed or devil's paintbrush, hardhack, briars, yellow devil, and brakes or ferns.

[5]The technical names are given for native pasture plants and shrubs because of the confusion existing in their common names.

The poorly drained wet meadows in Section 1a are usually occupied by bluejoint (*Calamagrostis canadensis*), marshgrass (*Spartina pectinacea*), Reed canary grass (*Phalaris arundinacea*), sedges, and rushes. Seaside bent is also found on many wet areas along the New England coast.

Southward in the eastern part of Section 1b poor pastures are characterized by the invasion of broom sedge, poverty grass, foxtail, crabgrass, and such weeds as chicory, buckhorn, bracted plantain, yarrow, sorrel, whitetop, and thistles.

In the western part of Sections 1a and 1b poor or neglected pastures are invaded by foxtail (*Aristida oligantha*), quackgrass, and such weeds as yarrow, ironweed, sorrel, buckhorn, knotweed, whitetop, shepherd's purse, and thistles.

Region 2.—This also was originally a forested region, but unlike Region 1 the predominating type of forest in the southeast was coniferous, composed of longleaf, loblolly, and slash pines on the Coastal Plain, and an oak-pine association at the higher altitudes. The native herbaceous vegetation following the lumbering operations in these forests is varied, but has a low nutritive value for the most part except in the spring. Grasses predominate and many of them, particularly the *Andropogon* and *Aristida* spp., are known locally as "wire grasses".

In Section 2a, which lies almost wholly in the cotton belt, the native grasses of most importance on cut-over land are *Andropogon scoparius*, *A. tener*, *Aristida purpurascens*, *Sporobolus gracilis*, *Panicum angustifolium*, *Gymnopogon ambiguus*, and *Andropogon elliottii*. Broom sedge (*Andropogon virginicus*) is abundant on land which has been cleared and abandoned for crops. The legumes found with these grasses in rather limited numbers are from the standpoint of abundance *Stylosanthes biflora*, *Galacta erecta*, *Lespede^a repens*, *Meibomia arenicola*, *M. marylandica*, and *Cracca ambigua*.

The improved pastures in Section 2a are almost wholly introduced grasses and legumes. Carpet grass on moist sandy soils and bermuda grass and lespedeza on loam, clay, and silt soils supply a large percentage of the pasturage in this section. Dallis grass and Johnson grass also contribute a great deal of pasturage, while the centipede, Rhodes, vasey, and rescue grasses have only a limited value because they are local in their distribution. Among the legumes in improved pastures lespedeza is by far the most important. The hop and bur clovers are widely distributed and white clover and black medic are important on soils which have a fair calcium content. Cluster and Persian clovers are later introductions which may find a place in southern pastures.

Section 2b is the subtropical belt along the Gulf of Mexico. Here, as in Section 2a, the native woods grasses in the "flatwoods" and on cutover land supply considerable grazing. Those most important are *Andropogon hirtiflorus*, *Sporobolus gracilis*, *Muhlenbergia expansa*, *Aristida condensata*, *Andropogon elliottii*, *A. virginicus*, and *A. tenarius*. The principal legumes found in association with these grasses are *Galactia floridana*, *Bradburya virginiana*, *Meibomia triflora*, *Cracca chrysophylla*, *Galactia volubilis*, *Crotalaria rotundifolia*, and

Chamaecrista fasciculata. There are many other grasses and legumes found by Reed[6] in his pasture surveys, *Aristida virgata* and *A. stricta* being perhaps the most valuable of these.

The improved pastures in Section 2b like those of Section 2a are largely carpet, bermuda, and centipede grasses, but in addition we find others such as bahia, para, guinea, molasses, St. Lucie, and natal grasses which are all confined to practically frost-free localities and are not, therefore, suited to Section 2a. The Natal grass, although abundant in the Florida peninsula is of little value for grazing because it is unpalatable. Pastures in Section 2b are notably deficient in legumes.

Along the Atlantic Coast from New Jersey southward the brackish marshes of the Coastal Plain are characterized by several species of *Spartina* (*Spartina alternifolia* and *S. patens*) and by sedges and rushes. In the swampy or wet lands of the interior in Sections 1b and 2a are found not only several species of sedges and rushes, but the tall reed-like grasses, small cane (*Arundinaria tecta*) near the Atlantic Coast and large cane (*A. gigantea*) of the lower Mississippi Valley. The latter formed the original cane brakes of our southern states. The reed (*Phragmites communis*) is distributed widely along water courses throughout the eastern states. All of these wetland grasses supply some pasture, but the reeds and canes of the fresh-water marshes are superior in palatability and nutritive value to those growing on the sandy and brackish soils near the coast. In the Everglades of southern Florida, saw grass (*Cladium jamaicense*) predominates; it is of little value for grazing purposes. Farther west in Section 2b near the Gulf Coast there is an abundance of pifinne (*Panicum hemitomum*) and some species of *Spartina* with sedges and rushes. The pifinne is not only grazed at certain times of the year, but is also cut, dried artificially, and ground for feed.

Region 3.—In Region 3, as previously indicated, a large proportion of the pasturage is supplied by the native short grasses. Forests as such are almost unknown in this region which is predominantly level upland with a gradually increasing altitude from the eastern border to the 5,000-foot contour line on the eastern side of the Rocky Mountains. Some trees are found bordering the streams on the chernozem or black soils of the eastern edge of this region. It is this black soil belt also that is really the transition zone between the prairies and the plains vegetation. Into this zone the bluestems penetrate quite freely, especially along the water courses and drainage channels which are ordinarily dry. At the bottom of such channels or low places the vegetation may be largely big bluestem, while on the rough banks or brakes little bluestem predominates. Along the actual water courses big bluestem occupies the bottomland and little bluestem in association with big bluestem the second bottoms, while the higher rougher land is an almost pure stand of little bluestem until the level upland is reached where the short grass begins.

[6] REED, H. R. Unpublished reports on botanical studies of reforestation plots at the Coastal Plain Experiment Station, McNeill, Miss., and pasture plots at the Chinsegut Hill Sanctuary, Brooksville, Fla., and the Penney Farms, Fla.

West of the chernozem soils in the zone of dark-brown and brown soils is found the true short-grass formation due mostly to the low rainfall but to some extent to the soil. Shallow-rooted plants thrive best on this soil because the carbonate layer is comparatively close to the surface and the subsoil is permanently dry. In the North the principal grasses are an association of blue grama (*Bouteloua gracillis*) and western needle grass (*Stipa comata*) with a small admixture of June grass (*Koeleria cristata*). The most characteristic weeds in this association are pasture sage (*Artemisia frigida*), silvery psorale (*Psoralea argophylla*), and the coneflower (*Echinacea angustifolia*.) On the heavier gumbo soils are both large and small areas of the western wheat grass (*Agropyron smithii*) useful both for pasture and as hay. This formation is confined mostly to North and South Dakota and the northwestern part of Nebraska. In northeastern Wyoming and eastern Montana, the vegetation is largely blue grama, but includes also nigger-wool (*Carex filifolia*) and June grass. Near the mountains the formation is often interrupted by sagebrush areas. In this northern part grasses are more readily established on abandoned crop land than in the southern part. Crested wheat grass. brome grass, and slender wheat grass may be grown successfully on such lands.

The middle section of the Great Plains in western Nebraska, Kansas, Oklahoma, and northwestern Texas has a very typical short-grass association of buffalo grass (*Bulbilis dactyloides*) and blue grama. In many places there are great expanses of an almost pure stand of these two grasses. Often, however, there is mixed in this basic formation taller grasses like western wheat grass, western needle grass, side-oat grama (*Atheropogon curtipendula*), and the three-awn grass (*Aristida longiseta*). Psoralea (*Psoralea tenuifolia*), prickly pear (*Opuntia lindheimeri*), and in wet years, horseweed (*Erigeron canadense*) and gum-weed (*Grindelia squarrosa*), are the most characteristic weeds.

Farther south below the Texas Panhandle the black grama (*Bouteloua eripoda*) and the curly mesquite (*Hilaria belangerii*) take the place of the buffalo grass and blue grama as the most important pasture plants. Here the turf becomes progressively more open as we near the Rio Grande River and the mesquite trees, soap-weed (*Yucca elata*), bear grass (*Yucca glauca*), and sacahuista (*Nolina erumpens*), as well as other desert plants, become more abundant. A narrow belt along the river is in reality an extension of the desert, Section 4b. All of the short-grass region supplies excellent pasturage, although the carrying capacity is much lower than that of tame pastures in humid regions.

The most important breaks in this short-grass vegetation are the sandhill section of Nebraska and the sandy soils of northwestern Oklahoma known as the "shinnery" lands. On these sandy soils we have mostly tall grasses rather than buffalograss and gramagrass. In the Nebraska sandhills the *Calamovilfa longifolia*, *Stipa* sp., *Sporobolus cryptandrus*, *Panicum virgatum*, *Andropogon scoparius*, *A. hallii*, *Bouteloua hirsuta*, *Muhlenbergia pungens*, and *Psoralea lanceolata*, along with the sandhill plum (*Prunus angustifolia watsonii*), are the most characteristic. In the "shinnery" we find bunchgrass, mostly

Andropogon species, associated with the shin oak (*Quercus havardii*). This oak is rarely over 3 feet in height and represents a transition to the southern desert shrub.[7]

In Regions 3 and 4, Section 5b and the drier parts of Section 5a, wherever irrigation is not practiced, the most effective method of improving the natural pastures is by proper protection of the native vegetation. This means a system of grazing which will not destroy the better, more palatable species. Such grazing systems, adapted to different parts of the arid intermountain area, have been developed by the Forest Service in the national forests and by the state and federal experiment stations in the Great Plains. Controlled grazing is absolutely essential to the protection of these lands from erosion and to their continued productiveness. Seeding these arid range lands with tame or introduced pasture plants has resulted for the most part in dismal failures.

Region 4.—The production per acre of pasturage in this region is the lowest of any of the five regions because the annual rainfall varies from 10 to 15 inches over most of it and in the central and southern parts is usually less than 10 inches. Only in the favored section around Moscow, Idaho, and Pullman, Wash., in the high mountain meadows, and in irrigated sections can any reasonable growth of tame pasture plants be expected.

In the northern part including western Montana, northern Idaho, northern Oregon, and eastern Washington, especially in the Moscow-Pullman section, thin stands of wheatgrass (*Agropyron spicatum*), little bunchgrass (*Fescue idahoensis*), and Sandberg's bluegrass (*Poa sandbergii*) are found. Where the rainfall is less abundant a bunchgrass condition of these same grasses, wheatgrass and *Poa* along with bunch wheatgrass (*Agropyron scoparius*), appears.

In southern Idaho, Utah, and Nevada the true desert shrub vegetation characterized by the large sagebrush (*Artemisia tridentata*), the shadscale (*Atriplex confertifolia*), and the salt sage (*Atriplex corrugata* and *A. nuttallii*) are encountered. The large sagebrush even extends east of the Rocky Mountains in Wyoming, Colorado, and Montana, as well as north into Oregon and Washington in certain unfavorable situations. During rainy periods the introduced annual brome (*Bromus tectorum*), filaree (*Erodium cicutarium*), and similar herbaceous desert plants spring up and furnish some grazing. Associated with the shadscale is the winterfat (*Eurotia lanata*), one of the most valuable grazing plants in the Great Basin. Sagebrush is found mostly north of latitude 34° except at high altitudes.

In the southern part of this region, including southern Nevada, southern Utah, and California and Arizona, and western New Mexico (Section 4b) at the lower altitudes sagebrush gives way to the creosote bush, the mesquite, and, on alkali soils, the greasewood. The rainfall varies from 2 to 20 inches and most of Section 4b has less than 15 inches, while temperatures often reach a maximum of 125° and rarely

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[7]Much of the information regarding Regions 3, 4, and 5 is adapted from Atlas of American Agriculture, Part I, Sec. E, Natural Vegetation, by H. L. Shantz and Raphael Zon, and from U. S. Dept. of Agriculture Misc. Pub. 101, Important Western Browse Plants, by Wm. A. Dayton.

fall below 25° F. Along with the creosote bush (*Covillea tridentata*) goes the desert saltbush (*Atriplex polycarpa*), narrowleaf saltbush (*Atriplex linearis*), mesquite (*Prosopis juliflora*), and chamisa (*Atriplex canescens*). There are also in this southern area a large variety of yuccas and cacti some of which grow to a remarkable size. Here, also, are palo verde (*Cercidium torreyanum*), catsclaw (*Acacia greggii*), lechuguilla (*Agave lechuguilla*), and sotol (*Dasylirion texanum*).

The best grazing areas are in eastern Arizona, western New Mexico, and the extreme western part of Texas. Here the larger part of the rainfall comes during the summer season and a few very drought-resistant grasses are found scattered among the desert shrubs. The most important of these are galletagrass (*Hilaria jamesii*), tobosa grass (*Hilaria mutica*), black grama (*Bouteloua eripoda*), crowfoot grama (*B. rothrockii*), six-weeks grama (*B. aristidoides*), and six-weeks needle grass (*Aristida adscensionis*). Even curly mesquite, one of the valuable grasses in the southern Great Plains, is found in rather thick stands at the higher altitudes in southeastern Arizona. All these grasses are palatable and nutritious.

Region 5.—The rather abundant rainfall in Section 5a, together with the mild climate, makes it possible to establish very high-producing tame pastures of introduced grasses and legumes in this section. Kentucky bluegrass, orchard grass, tall oat grass, timothy, meadow fescue, meadow foxtail, Reed canary grass, the ryegrasses, and the bent grasses thrive here. All of the clovers, but especially ladino, make bountiful pastures. Scarcely any other part of the United States is so well suited to these pasture plants and nowhere else, except on irrigated lands, do pastures have such a high carrying capacity. The most productive pastures are on the bottom lands. On the uplands are vast areas of cut-over lands and comparatively treeless prairie.[8] Here the natural grass cover consists of blue grass, bent grasses, fescues, bromes, velvet grass (*Holcus lanatus*), and white and hop clovers. Such weeds as buckhorn, bracken fern, sorrel, and cat's ear are abundant. Some of these lands have been burned over and seeded to Italian ryegrass, orchard grass, timothy, and red clover. On wet lands which are subject to flooding for short periods, the best pastures consist of seaside bent, meadow foxtail, Italian ryegrass, and alsike clover. On lands which are frequently under water for long periods Reed canary grass or seaside bent may be grown successfully.

The native grasses on the range along the mountains above the cultivated uplands and merging into the forests were originally populated with many of the bunch grasses which are now found east of the Cascade Mountains. Due to overgrazing these perennial bunch grasses have been largely superseded by annual fecues, bromes, wild oats (*Avena* sp.), and bur clover intermingled with deer brush and other woody browse plants.

In the southern part of the Pacific Slope, Section 5b, the rainfall is much less than in Section 5a, but is like it in respect to being very largely a winter rainfall. In the interior valleys, therefore, most of the pastures are irrigated like the fields which grow harvested crops.

[8] McCollam, M. E. Permanent pastures. Wash. Agr. Exp. Sta. Bul. 211. 1927.

Alfalfa is the most productive pasture in these valleys and is grazed more successfully here than in the eastern states due to less trouble with bloat. A pasture mixture found very satisfactory, particularly in the San Joaquin Valley south of San Francisco is a combination of Dallis grass, Italian ryegrass, alfalfa, and ladino clover. Such pastures have a high carrying capacity and can be grazed heavily with less injury than the pure alfalfa.

In the foothills, where desert-like conditions are encountered at the lower altitudes, the grasslands merge into the shrubby chaparral oak (*Quercus emoryi*) and scattered desert shrubs, mainly mesquite, creosote bush, yuccas, blackbrush, and cat's claw, similar to those on the eastern foothills of the Sierra Nevade Mountains. In the coast range the California chamiso (*Adenostema fasiculatum*), often called "Chamise" covers large areas and is one of the most characteristic chaparral species. In the Mohave Desert the picturesque Joshua tree (*Clistoyucca brevifolia*) is seen in scattered stands with wild buckwheat (*Eriogonum fasciculatum*) covering much of the ground underneath. On the drier slopes encelia (*Encelia farinosa*) forms dense thickets and on more humid slopes this is replaced by the California sage (*Artemisia californica*). None of these desert shrubs are of much value for pasture purposes.

The pasturage on these semi-desert lands consists largely of winter annuals which begin growth with the first rains in late fall and continue through the winter and early spring months. The most common of these are several brome grasses (*Bromus rubens*, *B. hordeaceus*, *B. tectorum*), wild oats (*Avena fatua* and *A. barbata*), squirrel-tail (*Hordeum murinum*), the legume bur clover (*Medicago hispida*), and an herbaceous spreading annual of the Geranium family known locally as filaree (*Erodium cicutarium*). Both the bur clover and filaree are nutritious grazing plants and very much desired on the ranges, but the annual grasses are low in nutritive value and most of them are objectionable because of their long awns. In protected areas two perennial grasses still persist. These are the California *Poa* (*Poa scabrella*) and California needle grass. (*Stipa pulchra*) Mountain rice (*Oryzopsis hymenoides*) is another perennial which is abundant in some localities.

In the numerous alkali areas salt grass (*Distichlis spicata*) is most abundant, but with it are tussock grass (*Sporobolus airoides*), rabbitbrush (*Chrysanthamus graveolens*), and alkali heath (*Frankenia grandiflora*).

The wet lands or marshes in Section 5b are occupied by Indian rice (*Zizania aquatica* and *Z. palustris*), cattail (*Typha latifolia*), and tule (*Scirpus validus*). Where these marsh lands in the Sacramento and San Joaquin valleys have been diked and drained, they provide very fertile farm areas especially for the production of truck crops.

RELATION OF GRASS COVER TO EROSION CONTROL[1]

H. H. BENNETT[2]

MUCH has been said and written about the powerful effect of forests, in controlling erosion and increasing absorption of rainfall, but not nearly enough attention has been devoted to the similar and almost equal effect of grass as a stabilizer of land and as an effective means of increasing absorption. The importance of grass as a means of controlling erosion is so great that this paper may appropriately be prefaced with the assertion that where there is a good cover of grass there is no serious problem of erosion. For this reason it seems time for agronomists and all of those who are interested in the continuing welfare of the crop and grazing lands of the nation to think more of ways and means for increasing the use of grass, and those other thick-growing crops that function after the manner of grass, to the end that by this simple procedure more of the water may be retained where it falls, with less of it running rapidly into the streams, and with more of the soil held in sloping fields where it belongs.

The results of careful measurements of the runoff and erosion from representative areas of 12 major soil types throughout the country show on the average that where grass, or a similar dense crop, is grown 5 times more rainwater is absorbed and 65 times less soil is washed away as compared with the losses of soil and water from exactly the same kind of land, occupying the same slope, and receiving the same rainfall, where clean-tilled crops are grown. These measurements have been made from about the average slope of the soil types involved, and they represent annual losses over a period ranging from 2 to 4 years. In one instance, that of the Colby silty clay loam of western Kansas, the average annual loss of soil from an area devoted to a clean-tilled crop (kafir corn) has been 3,300 times greater than on the same type of soil, occupying the same slope and situated at a distance of only a few feet, where the surface was thickly covered with a native growth of bluestem and grama grass; while the loss of water as immediate runoff has been 437 times greater from the clean-tilled area than from the one covered with grass. The losses from some of the other extensive soils have been quite in line with those of western Kansas.

SOIL AND WATER LOSSES

For example, on an 8% slope of the Shelby silt loam in the rolling part of the north Missouri corn belt, the average annual loss of soil over a 3-year period has been at the rate of 60.8 tons per acre, along with a loss of rainwater as immediate runoff amounting to 27.4% of all the precipitation; whereas, from the same degree of slope on the same farm the corresponding losses from Shelby silt loam under timothy grass have been at the rate of 0.32 ton of soil annually and 7.7

[1]Contribution from the Soil Erosion Service, Department of the Interior. Presented as part of a symposium on "The Relation of Pastures to the Land Utilization Program," before the annual meeting of the Society held in Washington, D. C., November 22, 1934. Received for publication December 10, 1934.

[2]Director, Soil Erosion Service.

of the rainfall. Where the ground was kept bare the corresponding annual losses have been at the rate of 112 tons of soil per acre, along with 26% of the rainfall. Inasmuch as the average depth of soil under the virgin prairie condition of the Shelby silt loam of this locality is approximately 7 inches on 8% slopes, only about 20 years would be required to remove the entire surface layer where corn is grown continuously. Where the ground is kept bare only 11 years would be required to remove the surface layer; but under grass 3,890 years would be required to remove the same depth of soil and under alfalfa 5,845 years would be required. In other words, in this region the probability is that soil builds up from beneath about as fast as it is removed from the surface under a good cover of grass or a good cover of alfalfa.

On February 23, 1934, the most astounding losses of soil occurred in the vicinity of Santa Paula, Calif., as the result of a heavy rain. On 17 farms where measurements were made immediately after the rain, it was found that steep slopes used for clean-tilled orchards had suffered acreage losses of soil ranging from 150 to 525 tons. That there were no measurable losses from the same kind of land on the same farms where the surface was covered with native vegetation is probably one of the most outstanding instances that we know of showing the utterly indispensable place that grass and other forms of stabilizing vegetation must be given in any plan having a chance to accomplish anything approximating permanency in our programs of erosion prevention and control.

COMBINATION OF CONTROL METHODS

It is unfortunate that some specialists have taken the position that erosion can be effectively controlled with a single engineering method of attack, namely, terracing. Terracing (the American type of terracing represents a broad embankment adjusted to slope contours) is generally an effective method for reducing erosion on slopes which especially in case of shallow soils with impervious subsoils, do not exceed about 6 to 10% in declivity, depending on the kind of soil, the degree of erosion as the result of past land use, the intensity of rainfall, and the type of agriculture. Supported by strips of grass, lespedeza, Sudan grass, or other adaptable thick-growing crops, terraces can be helpfully employed on somewhat steeper slopes, especially on those where the soil is deep and absorptive. This method for diverting water must also be recognized as a useful practical measure for carrying water from the upper sides of sharp, erosive slopes to safe drainage ways.

RELATION OF GRASS TO LAND DESICCATION

During the summer of 1934 numerous ranchers asserted publicly and privately that during the past 15 to 20 years, following the steady depletion of the grass by overgrazing, more and more springs have gone dry and numerous streams which formerly ran for considerable periods or throughout the year now carry water only for short periods following rains or the melting of snow. These complaints were frequently heard in Utah and southern Idaho. They were in some mea-

sure suggestive of what C. W. Hobley, a man of long experience on the continent of Africa, recently had to say in discussing the effects of overgrazing in East Africa. Mr. Hobley says, "We are thus confronted with the paradoxes that tsetse-fly is a blessing and water a curse. Where there is water, cattle are concentrated; they eat the grass—seeds, roots and all. With increase of cattle the soil is progressively removed and erosion sets in. To-day, two-thirds of Tanganyika are under the tsetse-fly, and in that two-thirds erosion merely follows the slow natural course. There is no doubt that two-thirds of Tanganyika have been preserved by the fly from erosion and ruination at the hands of the native population."[3]

It might be well to quote here part of a letter recently received from K. S. Sandford, Field Director of the Oriental Institute's prehistoric survey in northeastern Africa. Dr. Sandford says, ". . . the boundaries of the Nile are absolute desert, except within a few miles of the coast and in the Sudan. There is reason to suppose that the coastal belt provided grazing for larger flocks in ancient times than it now does (the Oriental Institute can cite you many inscriptions on this point): the coastal belt was the best wine-growing country in Roman times. There is a strong feeling among most of those who have studied the subject that the present state of affairs on the coast is due to (1) destruction during and before the Arab invasion (2) extreme neglect since that event, i. e. for about 400 years (3) perpetual grazing by goats, the most destructive animal in the world, and grazing of even the most sparsely vegetated regions by camels. It was the Arab who introduced the camel in large numbers into the country. To these factors rather than to any change of climate in the coastal belts is attributed the present state of affairs."

"The northern Sudan from Darfur to the Nile is experiencing a serious encroachment of desert from the north: . . . there is similar trouble with the fringes of the Kalahari and in northern Nigeria. In the arid or semi-arid Sudan also there is observable failure of formerly reliable wells. Some believe that these things are due to an arid period of a climatic cycle, which may be long or short. If you consider that since 1898, when settled government was given to the Sudan for the first known time in history, there have been no major losses of people or cattle, that the people and their flocks have increased by very many millions, that they have continued to live in country with 10-15 ins of rain and a tropical sun, and that they have done extensive cultivation, I think you can see that there may be something in common with your problems. If, now, you turn to Africa south of the Sudan, you see over-population, over-grazing, over-cultivation of exceedingly soft soil that washes away with the over-abundant rains (and will blow away, as in the Sudan, when it is dry). The result is appalling and forms perhaps the greatest problem of British administration in Africa. There is no serious suggestion of total failure of rain in this case."

A survey of a representative farm in Trego County, Kansas, where there was both eroded and uneroded land, made by R. H. Davis in 1931, shows that on this 159-acre farm, consisting in its upland por-

[3]Geographical Review, 24: 662. 1934.

tion of Colby silt loam that was broken out of the original plains grass in 1922, the principal erosional losses from 106 acres of cultivated upland were as follows: 29.3% had lost 3 inches of soil, 28.8% had lost 4½ inches of soil, 33.9% had lost 8 inches of soil, and 0.5% had lost 2 feet of soil and subsoil.

All the eroding areas were losing soil at a strongly accelerated rate, as compared with the areas still retaining a cover of plains grass, and all of this eroded land had suffered markedly in productivity. The most severely washed areas had become excessively droughty and had very little value for the regional crops. The exposed subsoil and the slope was essentially identical with subsoil which, at the Hays (Kansas) Experiment Station, produced on an average of 4.8 bushels of wheat as against an average of 25.2 bushels produced on the practically virgin soil in the same field where the slope and the methods of culture were identical. Here the soil loss from the virgin area has been at the rate of 2 tons an acre and from the corresponding subsoil at the rate of 11 tons an acre, with corresponding water losses of 10 and 19%, respectively.

It is interesting to note in this connection that the vegetation on the typical virgin soil of the Trego County area, which completely covered the ground, consisted of 85% of grasses (buffalo, little bluestem, and blue grama) and 15% of weeds; while that on the eroded soil, originally the same, after 2 years of abandonment consisted of no grass, 2% weeds, and 3% old Kafir stubble, with 95% of the surface bare. In other words, there had been a switch from a 100% ground cover of vegetation to a condition of 95% of non-vegetated surface, with not a single plant on the abandoned eroded area that was found in the original cover.

MORE VEGETATIVE METHODS OF CONTROL NEEDED

The evidence is sufficient to convince anyone that vegetation must be brought more and more into our plans for controlling erosion. One of the principal curses of the American type of agriculture is continuous clean cultivation of sloping erosive land. The decreased productivity and ultimate depletion of most of these lands with the continuation of such usage, is not a matter of opinion but a predetermined physical fact. In other words, if we are to preserve the body of our soils we must, as speedily as possible, change our farm methods on rolling land in a very marked way. We must practice more crop rotations; we must to an increased degree keep the land covered with thick crops at certain seasons of the year; we must bring strip cropping more into use; and numerous areas of steep, highly erosive land must be stabilized with grass, lespedeza, trees, or other soil-holding crops. In many fields these vegetative practices can be introduced and are being introduced in a practical manner and with the full approval of farmers where the farmer has been shown why and where they should be adopted. This can be accomplished in many instances either by demonstration or through the medium of a map showing the precise physical conditions of a farm and the relation of these conditions in the various parts of a farm to their needs. In the program of the

Soil Erosion Service, now being applied to many millions of acres, this is one of the basic procedures.

PLAN OF PROCEDURE

The method of attack employed by the Soil Erosion Service is essentially a coordinated plan of correct land use. This plan involves not only the use of direct methods of retarding erosion (which necessarily calls for retardation of runoff by increasing absorption of the rainfall), but the use of indirect methods, such as the retirement from cultivation of steep, highly erosive areas from which accelerated runoff (resulting from incorrect land usage) descends with destructive effect upon lower-lying cultivated areas. Such retired critically vulnerable lands are being planted with thick soil-holding crops, such as trees, grass, alfalfa, lespedeza, sorghum, and clover.

Part of the cultivated land is being protected with the new system of strip cropping, under which clean-tilled crops, such as cotton, corn, and tobacco (the real producers of erôsion), are being grown between parallel bands of grass, lespedeza, sorghum, and other dense crops planted across the slopes, on the level, i. e., along the contours. These latter crops catch rainwater flowing down the slopes, spread it out, and cause the suspended soil to be deposited and most of the water to be absorbed by the ground, thus protecting the crops growing on the plowed strips below. On certain slopes strips of permanent protective cover will be planted according to the French system, using trees, shrubs, and vines. Here is an opportunity to make advantageous use of nut trees, persimmon, honey locust (producing feed for livestock), briar crops, and other plants of economic value. It is hoped that it may be possible on some of the project areas to employ the Ecuadorian system of protecting steep slopes by bordering the downhill sides of rectangular fields with soil-holding hedges.

Field terraces (embankments adjusted to the contours) are being employed where applicable, and in some localities it is planned to scarify certain types of land, especially summer-fallowed ground, with a machine which scoops out 10,000 basin-like holes to the acre, each of which retains about 5 gallons of rain, causing it to sink into the ground where it falls. Machines for this purpose are now being manufactured. Soil-conserving crop rotations are being practiced and cover crops and other control measures are being employed.

Every farm is surveyed in advance of actual work by specialists of the local erosion staff. Soils, slopes, and extent of erosion are plotted on accurate maps. With the aid of this, the farmer, the erosion specialists, and the crops, engineering, and other specialists go over the farmstead, study it in detail and on the ground plan a course of procedure by assigning each acre to a particular use in accordance with its needs, adaptability, and appropriate place in a carefully planned, coordinated land-use program for that particular farm. The work is carried out on a strictly cooperative basis with the farmers. Generally, the latter are enthusiastically supporting every phase of the program. On some of the projects more than 95% of the farmers are going along with the program of the erosion specialists, agreeing to far-reaching reorganization of their fields and farm procedures. For

example, on numerous farms fences are being relocated so as to permit contour cultivation, terracing, strip-cropping, the inauguration of soil-building rotations, and the planting of the more vulnerable slopes to grass, trees, etc. Such hearty cooperation, it is believed, insures the success of the program. By putting through these initial educational watershed projects in a highly impressive manner, it is felt that it will then be possible to extend the work to all areas through the Extension Service, the colleges of agriculture, state experiment stations, and other organizations, with the assistance of erosion specialists when necessary.

FIRST COORDINATED EROSION-CONTROL EFFORT

Here is the first attempt in the history of the country to put through large-scale, comprehensive erosion and flood control projects, such as apply to complete watersheds from the very crest of the ridges down across the slopes to the banks of streams. These are not engineering projects, or forestry projects, or cropping projects, or soils projects, but a combination of all these, operated conjointly with such reorganization of farm procedure as the character of the land indicates as being necessary. This procedure is based on the best information in the possession of scientific agriculturists, agronomist, forester, range specialist, soil specialist, erosion specialist, agricultural engineer, economist, extension specialist, game specialist and, geographer. It is the application of accumulated knowledge pertaining to the great multiplicity of variables affecting the three-phase process of absorption, runoff, and erosion employed not as single uncoordinated implements of attack, but collectively, according to the needs and adaptability of the land, in a combination of integrated control measures, supplemented by new information accruing from the experience of combat.

No such coordinated attack has ever before been made against the evil of erosion in this country. Considering the physical, economic, and social factors involved, it is believed there is no other possible practical method of ever making any effective headway against this vicious problem. Even if the government owned the land, it would still have to be used over large areas in the production of crops and for grazing; and here again precisely the same physical problems would have to be met and conquered, an eventuality that unavoidably precedes all other consideration relating to correct land use.

EXAMPLES OF PROCEDURE

In the Wisconsin erosion project covering Coon Valley near La Crosse, for example, some of the steep timbered areas, now eroding because of excessive grazing, are being taken out of use and given complete protection in order to stop the excessive runoff of rainwater, which has been speeding down across the cultivated slopes, ripping them to pieces with gullies or planing off the more fertile topsoil. Grass is being restored to these protected forest areas, and where the trees are too thin other trees are being planted. Small plantings and seedings are being made that furnish feed and cover for quail and ruffed grouse. Eventually, with increased stocks of these fine game

birds, saved from starvation during prolonged periods of snow, as was done last winter, sportsmen will come from Milwaukee, St. Paul, Chicago, and other places to pay the farmer for the privilege of hunting in his timbered lands.

Below the forested land, the steep slopes now washing rapidly to a condition of low productivity are being taken out of the clean-tilled crops and put into permanent pasture to furnish the grazing that formerly was provided by the timbered areas. The grazing capacity of the farms is not thus increased or materially decreased, but the crop area is cut down to some extent. Better protection of the cultivated land from erosion will largely make up for this reduction by way of higher acreage yields.

On the 150,000-acre watershed erosion project on Big Creek in north-central Missouri, extending into south-central Iowa, a report of progress submitted by the regional director of the soil erosion work, under date of June 23, 1934, includes the following highly pertinent statement with respect to accomplishment, work having begun on this area in the spring of 1934: "At this time we have 401 cooperative agreements signed up with the farmers of the Big Creek project, and over 63,000 acres of land under contract for a coordinated plan of erosion treatment. We have been successful in reducing the corn acreage over the next 5-year period by more than 37 percent on these farms. We have cut the acreage of land where corn follows corn for a second year (a very bad practice) more than 54 percent. We have very materially increased the acreage of pasture. We are planning an intensive program on pasture improvement, beginning this fall and continuing into next spring. While weather conditions have been quite unfavorable, it is felt that very good progress has been made to date."

Thus, all indications point to successful achievement with these coordinated, educational programs of erosion control—which, it should be emphasized in conclusion, are of an experimental-demonstrational nature, and which, by reason of the necessary procedures involved with the accomplishment of a complete job, extend beyond the mere task of controlling erosion.

CONCLUSION

In conclusion, it should be emphasized again that a successful program of erosion control is going to call definitely for battling for more grass, more dense soil-stabilizing crops, and better adjustment of farm procedures to the physical characteristics of the land. The agronomist must hold a key position in this battle. It is hoped that he will distribute his forces so as to push the line of attack to every position needing attention.

ECONOMIC ASPECTS OF PASTURE IN THE LAND PLANNING PROGRAM[1]

C. L HOLMES[2]

TWO important factors have been responsible for pushing a consideration of pastures to the foreground in land-use planning. The first is the surplus crop production which has characterized our agriculture in recent years and the second is the conservation of soils and other natural resources. The first of these factors began to make itself felt in a tangible way in the depression of 1920 and 1921 and became acute with the present depression, culminating in the Government program to reduce surpluses of the crops in which the problem was most acute, and to adjust the acreage of crops and the number of livestock and the volume of the output of livestock products into a rational relationship with the existing and potential demand. The second of these factors we have had with us for many years, but it has been singularly overlooked in popular attention until the present administration embodied it in its comprehensive program of conservation and adjustment.

These two factors give ample justification for the importance which the pasture question has assumed. The issue, on first consideration, seems reasonably clear. We should shift substantial portions of land from erosive crops to grass, refit the organization of farms to this adjusted use of farm land, and achieve the double objective of reducing the total farm output of crops and livestock to a volume which corresponds to the demand for their use, and at the same time conserve in perpetuity our nature-given agricultural resources.

Unfortunately this solution meets with other forces which involve serious difficulties and make it much more difficult than it appears upon the surface. One of these forces is the pressure of people on farm land, induced by the large amount of unemployment in nonagricultural industries, which has been occasioned by the depression. Not only has there been a stopping of the normal flow of population from agriculture to industry, but there has developed a back flow of people from industry to agriculture which constitutes a resistance to the proposed program, the significance of which seems as yet only partly realized. More people on the land usually means more intensive use, whereas a greater dominance of pasture tends to mean less intensive use. There is the further factor of the individual farmer's interest in the proposal to place a larger proportion of land in pasture, and of his reaction to this proposal. Whatever the program, it must be worked out in the light of these two factors.

Finding the best ultimate place of pastures in the planning for agriculture must be worked out through a program that will reconcile these two sets of opposing forces. Such reconciliation will be extremely

[1]Contribution from the Division of Farm Management and Costs, Bureau of Agricultural Economics, U. S. Dept. of Agriculture. Presented as part of a symposium on "The Relation of Pastures to the Land Utilization Program," before the annual meeting of the Society in Washington, D. C., November 22, 1934. Received for publication January 17, 1935.

[2]Principal Agricultural Economist.

difficult, but there seems no reason for believing that it cannot be made. In its working out, both agronomists and economists have an important responsibility.

In the following discussion it is proposed, first, to present information on the place which pasture now holds in American farm economy; second, to discuss ways in which the use of pasture is involved in the farmer's problem of the organization and management of his farm; and, third, to present what appears to be the major points relating to pastures in land-use planning.

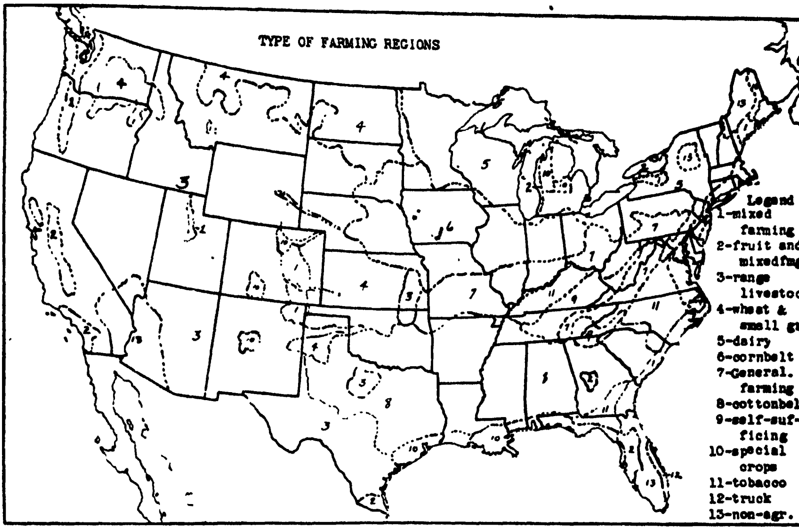

FIG. 1.—Location of regions listed in Figs. 2 and 5.

THE PLACE OF PASTURES IN AMERICAN FARMING

It will help to place our pasture problems before us to consider some data on the present place of pasture in American farming and the trends in its importance, and to compare the place it holds in our farming with its importance in certain foreign countries.

According to the 1930 census, there were in 1929 just a little less than a billion acres of land in American farms. Of this area approximately 89% was in pasture and crop land; the remaining 11% being in woods not pastured, in building sites, and in waste land. Of the land in crops and pasture, 52% was pasture and 48% was in crop land. Of the pasture, only 27% was reported as tillable. The remainder was pastured woodland and other untillable land used as pasture.

Fig. 1 shows 12 regions as blocked out for purposes of analysis by the Planning Division of the Agricultural Adjustment Administration. Fig. 2 shows the percentage of all farm land in pasture by these regions. An examination of Fig. 2 shows important variation in the relative importance of pasture. These variations, running from about 20% in truck farming to about 80% in the range livestock region, reflect the relative advantage of pasture and its uses under the differ-

ent physical and economic conditions that characterize the different regions.

It will be interesting at this point to compare the position of pasture in this country with its position in certain groups of foreign countries. Recalling the figures of 48% in crops and 52% in pasture as shown by the 1929 census for our own country, let us consider first a group of countries characterized by a very high percentage of farm land in pasture. In the Irish Free State, for example, crops occupy only 33%

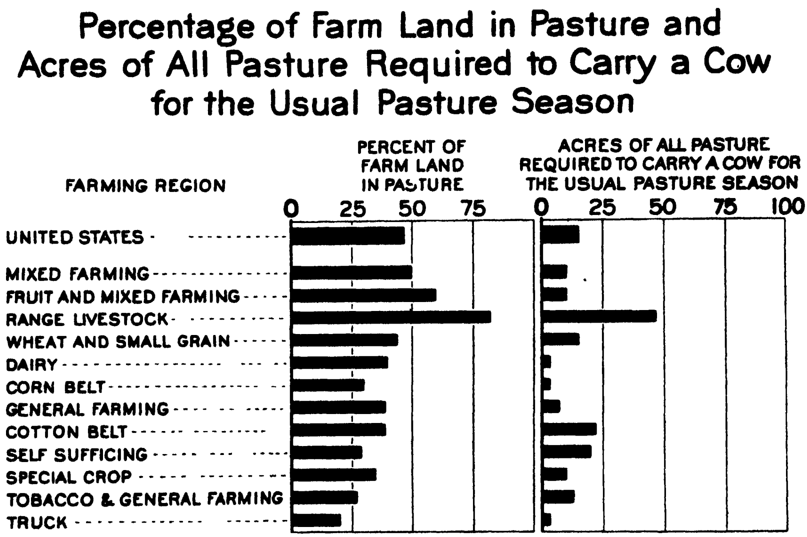

FIG. 2.—Nearly half of the country's farm land is in pasture, but its productivity in terms of feed units per acre is much below that of the land in harvested feed crops. Note the variations by regions in both percentage of land in pasture and its carrying capacity.

of the tillable farm land and pasture 67%. In addition, there is a large area of rough, untillable land which is also used for grazing. In the United Kingdom the "arable" land represents 37% and permanent grass 63% of the presumably tillable area. There is in addition a large extent of untillable land, part of which is used for the grazing of livestock. New Zealand represents the extreme in the dominance of pasture. Only 12% of the land which has been improved in that island country is in crops, whereas tame grass pasture occupies 88% and in addition there is almost an equal area in native grasses which is used for the grazing of livestock.

It has been suggested that the United States should follow the example of these countries which have apparently found that their best economic interest is served by keeping a very high percentage of their land in grass. It is further pointed out that the trends in land use in these countries have been toward more pasture and that this represents a rational adjustment to depressed conditions in agriculture.

There are special conditions affecting the adjustments in these foreign countries, however, which should not be lost sight of. They all have a marine climate, which tends to give pasture a higher comparative advantage than crops. This is partly for the reason that the production and ripening of grain is less successful than in the countries with a continental climate such as our own, and partly that these same climatic conditions are ideally suited to the production of grass and other pasture crops with an extremely high carrying capac-

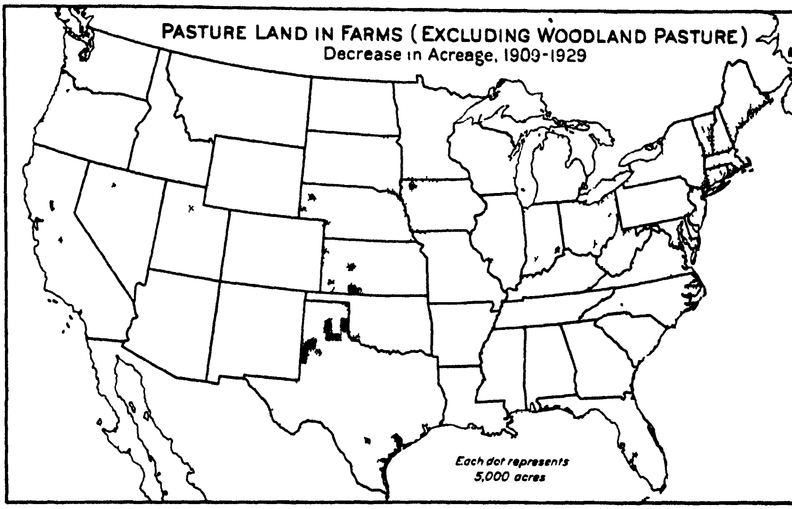

FIG. 3.—Decreases in pasture land in farms in the 20 years ending 1929 were very limited. Grazing land outside farms decreased in this period throughout the Great Plains by the establishment of new farms devoted largely to wheat growing.

ity. In the competition between these different land uses, therefore, it is not surprising that pasture has the ascendency.

In the case of New Zealand there is the additional factor of long distance from important consuming markets which makes it profitable to concentrate the products of the land into high-specific-value animal products which reduce the freight charges to a minimum.

In contrast with the figures from the countries just listed, we may take the example of certain European continental countries. According to the latest available figures from Germany, of the total acreage occupied by crops and pasture 71½% are in crops and only 28½% in pastures. In France these figures are 62% and 38%, respectively. This situation represents the results of a combination of factors including a continental climate, a relatively dense rural population which necessitates intensive use of land, and a type of farm economy characterized by a very high degree of self-containment.

Coming back to a consideration of the place of pasture in our own country, it is worth while to consider the trend in the importance of pasture. Figs. 3 and 4 show geographically the shifts in the use of

land for pasture between 1909 and 1929, as shown by the county census figures for those two years Each dot in these maps represents 5,000 acres Fig. 3, showing the areas in which pasture has decreased, reveals that in only a few scattered areas has there been any decrease. Most of this decrease is in the corn belt, notably in northwestern Iowa and adjoining areas, with some scattered decreases in other parts of the corn belt and in the northeastern states. Limited decreases are shown in the panhandle of Texas and in other portions of the Great Plains.

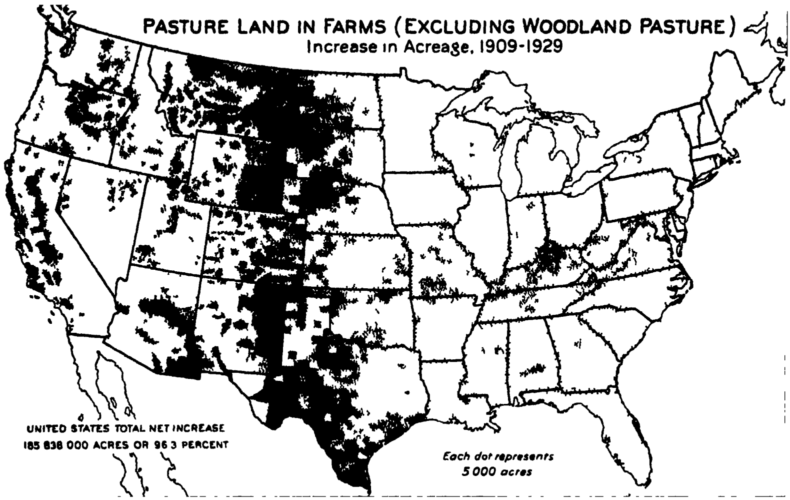

FIG. 4.—Increase in pasture area was general in the 20 years ending 1929. Most of the increase in the western half of the country is nominal rather than real since it represents old grazing land incorporated in new farms. In the eastern part the increase was actual and accompanied a decrease in the area in harvested crops

The decreases in the corn belt are in those areas favored with the most highly productive soil and most level surface, which give the production of grain a high comparative advantage. The decreases shown in the southern Great Plains represent for the most part the breaking up of grazing land for the production of wheat and cotton in response to factors such as mechanization, which led to the recent remarkable expansion in cropping in this region.

Fig. 4 shows than an increase in pasture acreage has been widespread and of very substantial proportions. Some of this increase, to be sure, is nominal rather than real. Throughout the Great Plains it represents, for the most part, the incorporation into actual farms of public land previously used for grazing, outside the boundaries of farms and hence not reported at all in the earlier census. As a matter of fact, there was a substantial shift out of grazing into crop growing in this region. On the other hand, the increase shown in the eastern half of the country represents a real shift from crops to pasture. The causes of this shift are various. A growing realization of the danger of

soil depletion is one of the most important. Another important one is a real decline in the comparative advantage of feed grains brought about largely by the introduction of tractor power and the accompanying falling off in the use of feeds in the support of workstock. Within this 20 years there was a temporary increase in grain production induced by the war situation which was followed by the resumption of the decline. These changes have been accompanied to some

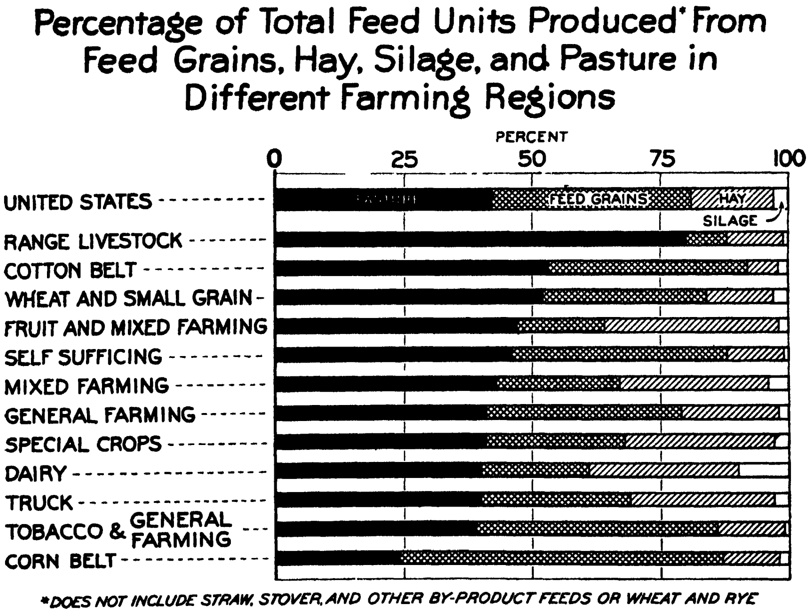

FIG. 5.—Note the small relative importance of pasture as a source of feed in the corn belt as compared with other regions. Hay is also relatively of little importance in the corn belt as compared with feed grains.

extent by an increase in the average size of farms and a decrease in the number of farms, but such changes are not so conspicuous as the major shift from grain to pasture.

The question of whether this progressive shift from crops to pasture in the eastern part of the United States has been continued since 1929 is hard to answer. There has been a substantial reduction in the acreage of all crops, partly due to drought and more recently to the Government's adjustment program, but available figures do not show conclusively that there has been a corresponding increase in pasture. The 1935 census will give comprehensive figures by which the change in pasture over the last 5 years can be measured. It seems probable that the movement which was so apparent up to 1929 was substantially slowed up by the pressure of the back-to-the-land movement.

Considering the importance of pasture as a source of feed, no entirely accurate figures are available. However, we have been making some careful estimates, the results of which are embodied in Fig. 5

which shows the estimated percentage of feed derived from pastures, from feed grains, and from hay and silage, respectively.[3]

Referring again to Fig. 1 in order to get the location of the regions for which data are shown in Fig. 5, we may examine the chart for what it reveals of the relative importance of pasture as a source of feed. It is estimated that for the United States as a whole, 42% of all available feed units are derived from pasture. On this basis of comparison, also, the regional variations are wide, again reflecting, as does the percentage of farm land in pasture, the differing comparative advantage of pasture. The corn belt, with its great natural advantage in grain production, shows by far the lowest position for pasture under existing farm practice.

One of the most important considerations determining the real importance of pasture is its carrying capacity. The second set of bars in Fig. 2 shows this factor, approximately, in terms of the acres per animal unit required to support livestock during the normal pasture season. The highest carrying capacity is to be found in the pastures of the corn and the dairy regions. This is explained by a combination of good soil, favorable climate, and relatively more careful management of pastures. Since pastures in these regions constitute a more important resource in the production of livestock products, they receive somewhat more attention than is characteristic in some of the other parts of the country. Even here, however, the existing average requirement of nearly 5 acres per animal unit reflects the very low quality of much of the pastures in their present condition.

PASTURE IN FARM ECONOMY

Before proceeding to a discussion of pastures in land-use planning, it may be well to consider a number of aspects of the problem from the point of view of the individual farmer. Emphasis in the phrase, "land-use planning," should be upon the word "use". It is the farmer who uses the land. Planning should proceed, therefore, with him and his interest as the focal point.

The first and most patent consideration in the farmer's reaction to the use of pasture, and to proposals for increasing the importance of the place it now holds in farming systems, is the relation of pasture to livestock production. Pasture and hay must obviously be used by livestock if their place in the farming system is to be economically justified; but the influence of the amount and kind of pasture on the amount and kinds of livestock and livestock products is not so obvious. The farmer must be concerned with getting a maximum utilization of all his productive resources; that is, he must get as large a net income as possible, and this means to a considerable extent the largest gross income. If a given proportion of his land must, for physical and economic reasons, be used for pasture, he must determine the kind and amount of livestock which will make best use of it. This depends partly on the nature of the pasture and partly on the relative prices he can get for different classes of livestock and of livestock

[3]Estimates made by R. D. Jennings, Agricultural Economist, Bureau of Agricultural Economics.

products. It also depends on the relation of his pasture resources to the other feeds he can raise or finds it most profitable to raise.

The importance of these relationships may best be illustrated by a consideration of the geographic distribution of the more important livestock enterprises. The dairy industry is largely localized where it is through the elements of soil, surface, and climate which make pastures and the production of hay and other roughage a more profitable use of the land than a system of land use involving higher acreage of feed grains and other grain crops. The farmer must supplement feed from these sources with adequate amounts of concentrates either grown or purchased. The proportion of these which he grows himself is largely determined by physical factors which make growing or buying of concentrates the more profitable.

Contrasted with this situation in the dairy region is that of the corn belt where natural conditions of soil, surface, and climate give production of feed grains a superior economic advantage. Farmers in these two regions have adjusted their livestock enterprises to these natural conditions which have all the essentials of economic forces. The chain of causation tends to run (1) from the nature of the land and climate, which determine the best utilization of the land in terms of specific crop and pasture systems and which yield specific proportions of the different feed elements, to (2) the kind of livestock systems which give the best economic utilization of these feeds. In areas where natural conditions give highest comparative advantage to a system in which carbohydrate feeds—that is, corn and similar grains—have a dominant proportion, the production of meat animals is dominant. In areas where pastures and legumes give the best use value to the land, dairying tends to be dominant.

This states the case only as a generalization. There are hundreds of modifying factors both physical and economic. The important point is that the proposals to increase pasture in specific areas must be made with due consideration of these factors that are so vital to the farmer. This is not to say that adjustments cannot and should not be made Farmers, like all other humans, have much inertia in their makeup. However, they know that their interest depends in large measure in maintaining an effective balance between pasture and livestock and between pasture and hay and grain in their land-use systems. Their chief weakness probably lies in their failure to recognize and act upon their opportunities to improve the productivity of pasture, and to make its actual competitive power against other land uses rise to its potential level. Much can probably be done in helping farmers to realize the opportunity to get a higher utilization of land through pasture improvement, effective crop rotations involving pasture, and a more effective combination of pasture and roughage with grains in their rations for livestock.

The foregoing leads to a consideration of the relation of pasture to the income and cost side of the farmer's problem. Much has been said and written on the advantage of giving pasture a larger place in the farming system because it means lower costs of production. It is pointed out that pasture requires much less labor per feed unit than do grain crops, and for this reason it has been assumed that a higher

proportion of pasture in the cropping system would be to the economic advantage of the farmer because it reduces his costs. This is an incomplete view of the problem. It is important to consider not only costs per unit but the total volume of output, because both of these things are factors in the farmer's gross and net income.

In a consideration of the cost side of this problem an important distinction between the two outstanding classes of costs in farm production is overlooked. This is the distinction between fixed costs and variable costs. Fixed costs are those that do not rise and fall, at least in the immediate period under consideration, with increases or decreases in the total volume of output. In farming they are represented by such important elements as the interest on investment in farm land, interest and depreciation on farm buildings and other land improvements, interest and depreciation on farm equipment, and the farmer's own labor and that of the family to the extent that it cannot find ready employment outside of the farming business. The variable costs, on the other hand, are those that rise and fall pretty much in proportion to the volume of output. They are represented by such farming costs as fertilizer, hired labor that can be engaged and released as the demand for labor on the farm is greater or less, and other elements which are directly connected with the nature and volume of the output of farm products.

The significance of this classification of costs in terms of the question as to whether it pays to increase or decrease pasture, lies in the fact that the fixed costs cannot be reduced by reducing the output, whereas the variable costs can be so reduced. It is a stubborn fact that fixed costs rather than variable costs dominate in the farmer's production. In systems of farming in which livestock and livestock products are the principal output, our figures show that these fixed costs constitute approximately 75% of the whole. It is obvious, therefore, that a reduction in total output of product means an increase rather than a decrease in the total costs per unit of product; and, so far as this single factor is concerned, if a shift to more pasture means a reduction in the total output, it means a rise in the cost per unit rather than a fall.

The key to the relationship of these considerations to the farmer's reaction to a proposal for more pasture is the relative productivity of pastures as compared with crops. We have no dependable figures on the relative productivity per acre of land in pasture as compared with land in feed grains. Under conditions favorable for the production of alfalfa a higher production of digestible nutrients can be obtained in the form of good alfalfa hay or pasturage than can be obtained from corn under normal yields. This is not true, however, of the average pasture now found on American farms. The great bulk of it is decidedly lower in productivity than the grain crops which could be grown on most of the tillable land which is in pasture or might be put in pasture. Certain rotation pasture crops, such as sweet clover and lespedeza, can compete to advantage with oats and other small-grain feed crops on lands that are suitable for such rotation pasture crops. Some of the bluegrass pasture in the areas of more favorable soil can probably compete on fairly even terms with these grain crops.

However, these high carrying-capacity pastures are the exception rather than the rule in American farming. If pasture is to occupy a more important position and take its place as a means of preventing soil erosion and the depletion of fertility which now presents such an acute problem, it is obviously necessary to build up the productivity of pastures. If they cannot be given a stronger competitive position as compared with grain crops, the proposal to increase the acreage in pastures will encounter almost hopeless resistance on the part of farmers.

These same considerations which have been discussed in terms of costs can probably be more effectively presented in terms of gross and net income from farming. A basic principle in private economy is that of maximum utilization of resources. It means that the farmer's motive in planning the use of his land, labor, and equipment is that of getting the largest possible income from them. Too often, it is true, this motive is considered from the point of view of a short-time return and does not consider adequately the longer time aspects of it. However, it is one of the most stubborn realities in the farming situation. It reflects the basis of the farmer's thinking in the use of his land. He insists on using it in the way which appears to him to promise the maximum income in terms of sale and direct household use of products. Since the fixed elements in his resources so largely dominate, this very largely becomes a matter of maximum gross income.

There is, to be sure, an important collective aspect of this matter in terms of the relation of supply and demand of the various farm products as they affect not only price but total income. The price of the product is one important element which the farmer must consider in reaching his objective of maximum utilization. His consideration of this factor is probably far from adequate because of his lack of understanding of economic forces. Moreover, he is at a fundamental disadvantage as an individual in considering it because his individual action matters so little in the whole alignment of forces which determine price. This is probably the most important reason back of the present agricultural adjustment program. However, even with the present machinery of adjustment, or under conditions which may result from a rational evolution of the present adjustment efforts, the farmer will still have a major responsibility in determining the use he makes of the things he has to produce with. It is important, therefore, that this fundamental motive in farm economy be given due consideration in the proposals for modifying the present position of pastures in American farming.

PASTURES IN RELATION TO LAND USE PLANNING

Let us now turn our attention to the more specific relations of pastures to land-use planning. While the more direct and objective aspect of this relation is that of the need to save the soil from the damaging effects of erosion as well as to build up and preserve an adequate supply of the elements of fertility, other factors of at least equal importance must be kept constantly in view. The ultimate objective in efforts to conserve natural resources is to strengthen the basis for an adequate standard of living. It is important, therefore, to keep in

mind that land is to be saved for use rather than for its own sake. The first consideration is as to how any given proposed measure will affect the economic welfare of the users, both present and future. If, for example, we are going to have in the future more people on the land depending directly on farming for their economic opportunity, this must be taken into account in determining the place we propose to give to pastures in a farm land planning program. Can we utilize the products derivable from an appreciably higher proportion of pasture in a way to realize maximum benefits from our land resources? Can we by this means maintain a production of all of the various agricultural products rationally balanced with the needs of our people?

These questions imply the importance of a well-rounded consideration of all of the legitimate objectives and all of the forces and conditions involved in land-use planning. Difficult as it is to reconcile all of the conflicting interests and considerations, it is not unreasonable to expect that the motive of saving the land and that of realizing an adequate food supply and an ample economic opportunity for those engaged in farming are not antagonistic but can be harmonized into ultimate realization.

We can probably best get at the concrete phases of the relation of pasture to the need for planning future use of land by a study of the present situation in certain so-called problem areas. Fig. 6[4] shows the percentage of the total crop and pasture land in farms in 31 such areas occupied by (1) intertilled crops, (2) non-intertilled crops, and (3) pastures These areas are all in the eastern and more humid portion of the country.

Inspection of this chart shows that the intertilled, and hence more highly erosive crops, have their highest relative importance in the areas of the cotton belt. A peculiarity of the prevailing types of farming systems in the South is that there is no essential relation between the chief crop, cotton, and livestock. In most other areas where livestock is grown there are important supplementary and complementary relations between the crops and the livestock and hence a more intimate relation between these crops and pasture. This is not true of cotton, since it is not a feed crop and is not essentially tied up with the other activities of the farm except as such activities interfere with the labor demands of the cotton crop. Since cotton must be intertilled and since, as the chart shows, it is so much more important than the non-intertilled crops, there tends to be almost constant use in cotton of the land best fitted for it. The poorer land is naturally relegated to pasture and there is extremely little in the way of crop rotation, particularly as it involves pasture. This condition encourages erosion, augmented to a considerable degree by the fact that the frost-free season amounts to almost the entire year, thus giving the land but little rest from the effects of soil-depleting forces. It is under these conditions that erosion has reached its most advanced stage.

The non-cotton areas shown in the chart have a very low percentage of intertilled crops and a high percentage of pastures. In most of these areas livestock constitutes a tie between crops and pastures and

[4]Data supplied by W. W. Wilcox, Agricultural Economist, Agricultural Adjustment Administration.

tends to minimize the effect of erosion. In most of these areas also non-intertilled crops, mostly hay, which is an erosion preventive,

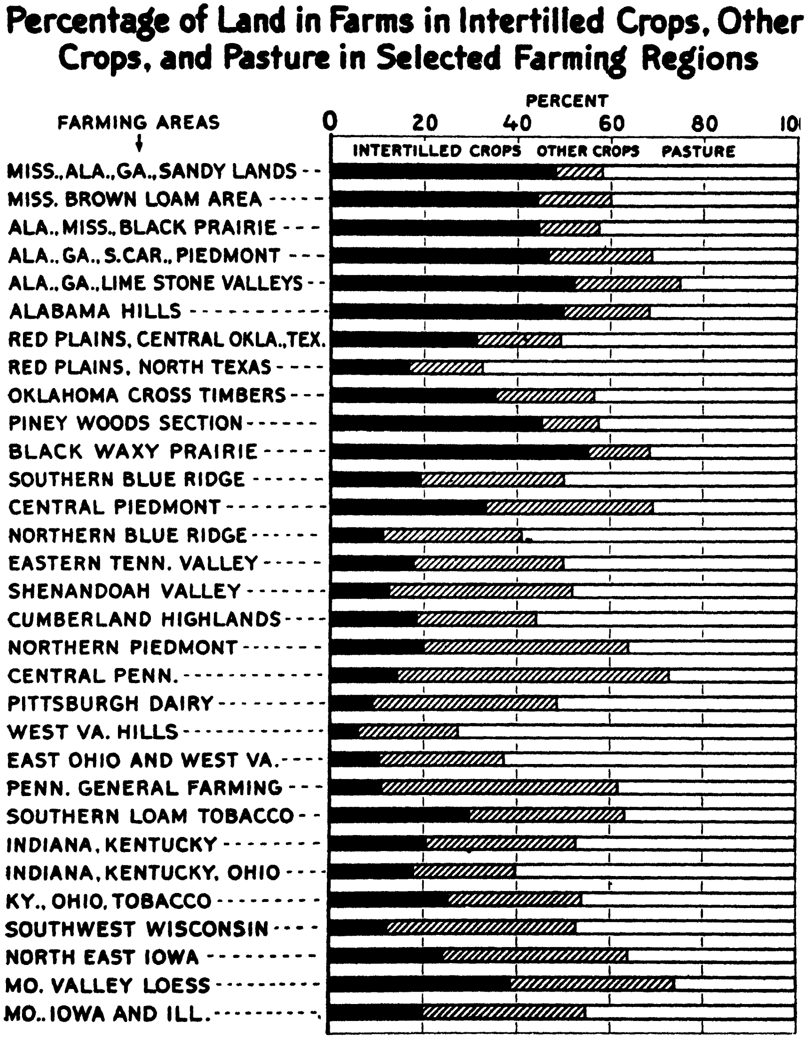

FIG. 6.—Note the high relative position of intertilled crops in the cotton areas as compared with other areas. Note their low position in the hillier areas.

exceed intertilled crops in importance. This means that there is opportunity to keep the intertilled crop area in grass for a part of the rotation period, and thus to minimize the effects of erosion. This system of farming represents a fairly satisfactory adjustment of the cropping and pasture system to the nature of the land.

In the corn belt areas, as shown by the chart, there tends to be a practically even distribution between intertilled crops, non-intertilled crops, and pasture. In this region the winter months are a resting period with reference to erosion forces and there is the closest sort of relation between the two classes of crops grown and the pasture. This relation arises from the important livestock enterprises which are themselves built upon the products of the land. Here, again, a fairly workable adjustment has been achieved.

Going over the different parts of the country once more for brief comments with reference to points of policy and planning on the matter of pasture in the cropping systems, it would appear that the southern problem is largely that of preserving an adequate acreage of crop land and of keeping up its productive quality; this in the face of the difficulties inherent in the farming system and the climate which makes the prevention of erosion very hard. It is probable that as time goes no more emphasis will be placed upon pasture, feed crops, and livestock as a regular though minor source of farm income in the South. However, the natural disadvantages of such a system in this region as compared with the present specialized livestock areas, together with the economic and physical conditions which give cotton its unquestioned ascendency, seem likely to make this solution of the problem only a partial one. Something must be done to preserve the quality of the best cotton lands, which represent the heart of the agricultural resources of the South. The protective possibilities of cover crops is an important element in the solution of this problem and has at least an indirect bearing upon the pasture problem. However, the pasture problem itself centers more specifically in the minor developments already referred to, namely, the growth of feed crops and pasture to support a limited livestock enterprise. In this relation pastures can no longer be looked upon merely as a vacation for worn out land. The questions of their vegetation and management must be taken up not only from the point of view of resuscitating land fertility but in connection with their use as a direct source of income through livestock.

Throughout most of the areas in the North, it seems questionable that any very substantial further movement toward permanently shifting land from crops to pasture can be economically maintained. The solution of the problem in most of these areas would seem to be in the direction of preserving from loss the present crop land without taking it permanently out of crops. This means, for the most part, a greater attention to effective rotations involving legumes which will not only contribute to erosion prevention through providing a larger amount of humus in the soil, but will raise the yields of grain crops so that the same amount, or at least an adequate amount, of grain crops can be raised upon a more limited acreage, thus making it possible to keep a larger proportion than at present of the crop land in soil-conserving crops which, incidentally, means enhanced pasture resources. In most areas, provided suitable soil-building crops can be found, the gain in yield per acre will be enough to compensate for the reduced acreage occasioned by the soil-building crop in the system.

One of the outstanding needs in this connection is the development and popularization of an acid-tolerant legume which will function in the acid-soil areas in approximately the same way that sweet clover is coming to function in the sweet-soil areas. Lespedeza is such a crop, but its present adaptability places a northern limit to its territory somewhere in the southern half of the corn belt. At present the greatest hope for this sort of crop in the northern half of the corn belt and in the dairy region seems to be sweet clover. But the necessity of incurring the heavy costs involved in liming the land to make sweet clover a safe crop is an effective bar to its very wide development, at least under present economic conditions. Probably no greater contribution to the preservation of the soil of the Middle West and the improvement of cropping systems from the point of view of the support of livestock could be made by the agronomists than that of discovering, developing, and popularizing a successful acid-tolerant legume crop which would fit as well into cropping systems on the acid soils of the corn belt and the dairy region as sweet clover does now on the sweet soils.

It has been suggested in many quarters that the increase in pasture land, which is assumed to be needed in certain hilly sections particularly of the southern corn belt and in other areas throughout most of the agricultural portions of the country, might be greatly facilitated by the consolidation of farms, which is assumed to be needed in order to provide an ample economic holding under a condition of the less intensive use of land represented by a pasture system. It seems feasible, from an offhand consideration, to plan for converting considerable areas of hilly farm land, now in relatively small farms, into larger grazing holdings almost to the exclusion of crop growing. When one goes into the factors involved in such a proposal, he encounters what will probably prove to be serious barriers to the successful carrying out of the plan. In the first place, with the back-flow of population from industry to agriculture, we can ill afford to reduce the number of farms. Thousands of farm families with recent farm experience are now living on relief in the cities and towns of our agricultural regions because they have been displaced either as tenants from the farms of landlords who had to move back on their farms to make their own living or through foreclosure of mortgages in the case of owner operators. Presumably, many other thousands of men recently employed in industry but now out of employment, who have an agricultural background, are potential competitors for the opportunity to occupy and run a farm. The case must be made air-tight to justify a reduction in the number of farms under the present conditions. Such justification is probably limited to the plainly submarginal situations where the land is being cleared by the Government to be converted into grazing reserves or consolidated holdings for grazing enterprises. This is particularly exemplified by situations in the Great Plains and other portions of the grazing region.

Another consideration in connection with the proposed consolidation is the question of whether the pasture type of use which is contemplated will support the investment involved in building up a larger holding. Assuming that the present systems of use of such land

yield a larger current income per acre than this land would yield if used entirely or mostly for pasture, we have a competitive element which must be faced in considering the new proposal. Lower use must be accompanied with lower investment per acre in order to be successful. It looks as if it were not possible, in the face of the present competition for farms, to scale down these values to a pastoral-use-returns basis.

CONCLUSION

Summing up the considerations so loosely discussed in the foregoing, we may condense them into four propositions, as follows:

1. The first objective in considering the expanded use of pasture is to make a better present and long-time opportunity for the people on the land. This does not mean merely a place on the land for those unfit for farming; but in the long run, if opportunity for industrial employment continues to be lacking, we must look for a higher percentage of our people on farms solely through the results of less migration from farms to industry.
2. The second objective would seem to be to save the land and make it more productive. This and the first objective, are, in the long run, compatible and harmonious. Their realization involves conservation of land with the use of land.
3. Contrary to the recent assumption that the service of those whose life work had been devoted to means of making the farmer more efficient and his land more productive are now outdated and unneeded, it would seem that the present situation and its demands require more service from these men than ever before. Consequently, the agronomists concerned with the development of pastures and other forage crops have a broader and more important responsibility. They share this responsibility with soil specialists, economists, and many others whose services are needed in meeting the new problem.
4. Finally, in all of this work there is needed, as the condition of a successful outcome, a happy balance between vision and good sense.

SOME LIMITATIONS OF PLANT JUICE ANALYSES AS INDICATORS OF THE NUTRIENT NEEDS OF PLANTS[1]

J. M. POEHLMAN[2]

IN an investigation on the adaptation of Morse and Virginia varieties of soybeans to different soil types, studies were made of the concentrations of nitrates, phosphorous, and potassium in the expressed plant juice of the two varieties. If any differences in concentrations existed, it was thought that they might help to explain the yields of these varieties as manifested on different soil types in different seasons. In addition to the contribution to the problem of varietal differences, an analysis of the data shows many observations on and some limitations of the use of plant juice analyses as indicators of the nutrient needs of plants which are summarized and presented here.

REVIEW OF LITERATURE

Gilbert (4)[3] determined the nitrogen, phosphorous, and potassium of plant extracts by colorimetric methods and found a relationship between the amounts of the elements present in the plant juice and the amounts of the corresponding fertilizing elements added to the soil. Gilbert, McLean, and Adams (6) found concentrations of nitrates, phosphates, and potassium in the plant juice influenced by factors which would limit or inhibit growth, such as deficient amounts of fertilizing elements, and unfavorable weather and cultural conditions. Critical concentrations of nitrates, phosphates, and potassium which should be maintained in the plant sap for optimum yields are suggested by Gilbert and Hardin (5) who found that the current amounts of these elements in plant extracts are influenced materially by the amounts supplied the crops in chemical fertilizers.

The lowering of the freezing point of cell sap by the application of fertilizers to the soil is reported by McCool (9). He suggests that a phosphorous deficiency in the soil may be detected by cell sap studies of crops grown on it. Austin (1) reports that soil type and the application of phosphorous and potassium fertilizer affects the phosphorous and potassium content of the cell sap of soybeans grown in the greenhouse. He believes the soil type to be a greater factor in determining the composition than the application of moderate amounts of fertilizers. McCool and Weldon (10) observed that the application of mineral nutrients to the soil as fertilizers generally resulted in increased concentrations of those elements in the juice and that if one element was limiting, the others would accumulate in the plant juice. Fonder (3) reports that variations were found in the potassium content of the expressed juice from stems and leaves of plants grown on different soil types, but these variations were not related to soil texture. Cook (2) studied the effect of soil type and fertilizer on the nitrate content of the expressed sap of small grains and reports the nitrate content of the sap to be increased by applications of nitrogen fertilizers, but to be decreased by the application of other fertilizers that

[1]Contribution from the Department of Botany, University of Missouri, Columbia, Mo. Received for publication December 15, 1934.

[2]Instructor in Field Crops, formerly Graduate Assistant in Botany. The author expresses his appreciation to Dr. W. J. Robbins under whose direction the investigation was carried out.

[3]Figures in parenthesis refer to "Literature Cited," p. 206

increased plant growth. McCool and Weldon (11) report that concentrations of phosphorous, potassium, and calcium in the expressed sap of small grains are reduced by the application of nitrogen fertilizers.

Pettinger (12) found correlations between the nitrate, phosphorous, and potassium concentrations in the expressed sap of corn plants growing on fertilized plats and the fertilizers applied. Three concentration levels of mineral nutrients in the expressed sap are tentatively suggested as indicators of very deficient, moderately deficient, or ample concentrations of nitrogen, phosphorous, and potassium in the soil. In a later paper Pettinger (13) reports an increase in the chlorine content of the expressed sap of corn with the use of chlorine-carrying fertilizers. A residual effect is exerted by the chlorine after 15 years. Pierre and Pohlman (15) report a higher concentration of phosphorous in the exuded sap of corn than in the displaced soil solution. In a later paper they (16) report the phosphate content of the exuded sap of corn grown in the greenhouse to be higher than when the corn is grown in the field. The authors suggest that many factors must be considered before establishing critical concentrations to determine a deficiency of available phosphorous in the soil.

MATERIALS AND METHODS

The plants used in the investigation reported here were Morse and Virginia varieties of soybeans which had been grown in field test plats located on Putnam silt loam, Lebanon silt loam, Oswego silt loam, and Wabash heavy clay. With the exception of the Wabash heavy clay, four fertilizer treatments were applied to each of these soils. The treatments and the rates of applications were as follows: sodium nitrate, 100 pounds; superphosphate, 250 pounds; muriate of potash, 100 pounds; a 4–16–4, 250 pounds; and fine lime, 250 pounds.

In the second season (1933) the plants were grown on the same soil types with the exception of the Wabash heavy clay. No plants from fertilized plats were used for analyses this year except on the Putnam silt loam where the soybeans were grown on the plats used the preceding year and the fertilizer applications repeated.

In making the analyses, plants were secured from five replications on each fertilizer treatment and a composite sample made. From this sample, the juice was pressed out and analyzed for nitrates, phosphorous, and potassium. Plants were secured for analysis when the first pods began to appear to keep the maturity as uniform as possible between the soil types. All samples from a soil type were taken the same day, and conditions were kept as uniform as possible throughout the procedure of sampling and analysis. The entire plants were ground in a food chopper and the juice pressed out with a small "Carver" hand-operated hydraulic press. A pressure of 5,000 pounds was applied and the press cake allowed to drain for 5 minutes. The juice was centrifuged at 2,000 r. p. m. for 10 minutes to remove suspended material. Ten-cc samples were pipetted into evaporating dishes and dried over a steam bath. The samples to be used for phosphate and potassium analyses were placed in an electric muffle furnace and heated for 2 hours at a dull red heat until only a white ash remained.

The nitrate nitrogen in the plant juice was determined by the phenoldisulfonic acid method as reported by Pettinger (12). Preliminary clarification and decolorization of the sap were made according to the methods described by Hill (8). Phosphorous and potassium analyses were made on the samples of plant juice which had previously been ashed. Phosphorous was determined colorimetrically as that soluble in 0.2 N hydrochloric acid after the method described by Zinzadze (18).

Potassium was determined colorimetrically as that soluble in 3% acetic acid after the method described by Herzner (7). So far as the writer knows, no report has been made in the literature regarding the application of these methods of phosphorous and potassium analysis to plant extracts. Soil analyses of available phosphorous and potassium were made colorimetrically by the same methods used for analysis of the plant juice. The soil solutions were obtained by shaking the soil sample with 0.2 N hydrochloric acid.

RESULTS OF EXPRESSED PLANT JUICE ANALYSES

The results of the chemical analyses of the expressed plant juice of Morse and Virginia soybeans grown on different soil types and with varied fertilizer treatments in 1932 are presented in Table 1 and the results for 1933 in Table 2.

TABLE 1.—*Results of analyses of expressed plant juice, 1932.*

Soil type	Variety	Soil treatments				
		Sodium nitrate	No treatment	Super-phosphate	4-16-4 and lime	Muriate of potash
		Nitrate Nitrogen*				
Lebanon......	Morse	69.7	32.3	49.9	28.3	39.5
Lebanon......	Virginia	30.9	24.5	49.9	28.2	39.6
Oswego.......	Morse	23.8	30.7	23.3	28.6	26.0
Oswego.......	Virginia	33.5	27.3	24.4	32.6	38.1
Putnam.......	Morse	32.0	76.2	38.4	40.6	38.9
Putnam.......	Virginia	26.5	49.8	42.5	42.4	40.3
Wabash.......	Morse	—	63.3	—	—	—
Wabash.......	Virginia	—	65.7	—	—	—
		Phosphorous*				
Lebanon......	Morse	106.1	77.5	73.6	77.8	63.7
Lebanon......	Virginia	74.1	64.5	69.8	64.9	71.4
Oswego.......	Morse	117.7	121.8	117.4	109.2	133.4
Oswego.......	Virginia	120.0	131.3	114.1	118.2	115.3
Putnam.......	Morse	78.8	80.4	59.6	64.0	80.0
Putnam.......	Virginia	80.4	77.3	63.5	76.1	122.4
Wabash.......	Morse	—	70.5	—	—	—
Wabash.......	Virginia	—	58.9	—	—	—
		Potassium*				
Lebanon......	Morse	3,956.2	3,989.2	3,866.2	4,415.0	3,821.8
Lebanon......	Virginia	3,501.9	3,617.4	4,144.9	3,471.8	3,938.1
Oswego.......	Morse	1,157.4	944.2	1,344.0	1,971.0	1,806.4
Oswego.......	Virginia	1,606.4	1,459.4	1,344.4	1,971.5	1,732.3
Putnam.......	Morse	4,373.7	4,506.8	3,521.2	3,396.5	3,931.0
Putnam.......	Virginia	3,643.4	4,463.7	3,967.3	2,855.7	3,931.5
Wabash.......	Morse	—	4,769.3	—	—	—
Wabash.......	Virginia	—	4,393.9	—	—	—

*Figures denote nitrates as p.p.m. of N; phosphorous as p.p.m. of P_2O_5; and potassium as p.p.m. of K_2O

TABLE 2.—*Results of analyses of expressed plant juice, 1933.*

Soil type	Variety	Soil treatments				
		Sodium nitrate	No treatment	Super-phosphate	4-16-4 and lime	Muriate of potash
		Phosphorous*				
Lebanon......	Morse	—	54.0	—	—	—
Lebanon......	Virginia	—	54.7	—	—	—
Oswego.......	Morse	—	103.2	—	—	—
Oswego.......	Virginia	—	90.7	—	—	—
Putnam	Morse	206.0	139.0	177.3	186.2	167.6
Putnam... .	Virginia	187.5	125.8	146.0	162.1	174.3
		Potassium*				
Lebanon.. .	Morse	—	10,607.5	—	—	—
Lebanon.. .	Virginia	—	8,663.6	—	—	—
Oswego..	Morse	—	4,290.0	—	—	—
Oswego.. . .	Virginia	—	5,690.0	—	—	—
Putnam. ..	Morse	9,240.0	5,575.0	5,960.0	6,970.0	11,050.0
Putnam	Virginia	7,895.0	5,935.0	6,310.0	10,655.0	11,145.0

*Figures denote phosphorous as p.p.m. of P_2O_5 and potassium as p.p.m. of K_2O.

ANALYSIS AND DISCUSSION OF RESULTS

An examination of the data in Tables 1 and 2 shows them to be affected by several factors. The controlled factors in the experiment which cause variations in the data may be divided into four groups, *viz.*, varieties, fertilizer treatments, soil types, and years or seasons. The variance due to each of these groups may be segregated, measured, and tested for significance. Within each of these groups the concentrations of mineral elements in the plant juice are affected by a number of conditions whose variance cannot be segregated and measured. These conditions are experimental error in sampling and analysis, variations due to age or maturity of plants, moisture content of plant, rate of growth, soil heterogeneity, and climatic factors, such as light, temperature, rainfall, humidity, and soil moisture. The concentrations of mineral elements in the plant juices may also be altered by interaction of soils and varieties, soils and fertilizer treatments, varieties and fertilizer treatments, and the interaction of each of these with seasons.

The variance due to each of the factors in the experiment—varieties, treatments, soils, and seasons—will be analyzed and discussed. Also the relation of plant juice analyses to soil analyses and its corresponding correlation to yield will be presented.

The results of an analysis of variance (17) applied to the nitrogen, phosphorus, and potassium concentrations in the expressed plant juice of Morse and Virginia soybeans for 1932 are given in Table 3. The analysis takes into consideration only the data from the three soil types, Lebanon, Oswego, and Putnam, as given in Table 1.

TABLE 3.—*Analysis of variance of nitrogen, phosphorous, and potassium concentrations in expressed plant juice of soybeans, 1932.**

Source of variation	Degrees freedom	Sum of squares			Mean square		
		N	P	K	N	P	K
Total variance..	29	.4596	1.7579	40.5361	—	—	—
Variance between means of varieties..	1	.0078	.0001	.0612	.0078	.0001	.0612
Variance between means of treatments	4	.0147	.1003	.1673	.0037	.0251	.0418
Variance between means of soils.....	2	.1053	1.2558	36.2532	.0526	.6279	18.1266
Variance due to interaction:							
Varieties—soils...	2	.0257	.0894	.2821	.0128	.0447	.1410
Varieties — treatments..........	4	.0397	.0304	.4855	.0099	.0076	.1214
Soils—treatments.	8	.2169	.1820	2.7016	.0271	.0228	.3377
Remainder—experimental error.......	8	.0495	.0999	.5852	.0062	.0125	.0731

*Decimal points were moved two places to the left for calculations of N and P and three places to the left for calculations of K.

VARIANCE BETWEEN MEANS OF VARIETIES

By the analysis of variance we are able to segregate for that season the variance in the concentrations of elements in the plant juice due to varieties, soils, fertilizer treatments, and to interaction. We may then test the significance of the variance in the concentrations attributed to differences in varieties by comparing its mean square with the mean square of the remainder which we attribute to experimental error and other uncontrolled factors in the experiment. An examination of the mean squares in Table 3 reveals that the variance due to varieties is not significantly different from the variance due to experimental error. This signifies that we cannot measure any significant differences between Morse and Virginia varieties of soybeans by chemical analyses of the expressed plant juice for nitrogen, phosphorous, or potassium.

A comparison of the mean squares of the variance due to interaction with the mean squares of the remainder reveals no significant differences for either nitrate, phosphorous, or potassium concentrations. This means that the measured differential effect between the varieties and the different soil types and fertilizer treatments is not significant.

VARIANCE BETWEEN MEANS OF FERTILIZER TREATMENTS

No significant differences may be found by comparing the mean squares of the variance between means of treatments and experimental error. This indicates that we cannot measure any appreciable effect of fertilizer treatments on the concentrations of nitrates, phosphorous, and potassium in the expressed plant juices of soybeans in 1932. These are contrary to the results of previous investigators (5, 1, 10, 2, 11, 12, 13, 16).

In measuring the effect of fertilizer treatments by plant juice analysis, it is important to distinguish between plants grown in pot experiments (4, 1, 10, 16) and in field plats, and also between the time and rates of fertilizer applications. Pohlman and Pierre (16) report higher concentration of phosphorous in the exuded sap of plants grown under greenhouse conditions than when the plants are grown on the same soils under field conditions. With extremely high rates of fertilizer applications (6, 9) we may expect a greater effect on the plant juice analyses than with moderate applications. When fertilizers have been applied to field plats over a period of years, an analysis of the plant juice measures the residual effect of the fertilizer (2, 12, 13) as well as the effect of the current treatment.

It is possible that the fertilizing elements did not go into solution in the soil in time appreciably to affect the plant juice analysis in the 1932 season. On the Putnam silt loam the fertilizer applications made in 1932 were repeated before planting in 1933. The results are illustrated in Fig. 1. In the plant juice analysis made in 1933 on this soil type not only the effect of the current fertilizer applications, but also the residual effect from the previous year is being measured. These results indicate that moderate fertilizer treatments will materially affect the plant juice analyses if they have ample time materially to affect the soil solution. The variance in the concentrations from "no treatment" plats as well as a corresponding variance from the fertilized plats between the years may be attributed to differences in the climatic and soil moisture conditions of the two seasons.

VARIANCE BETWEEN MEANS OF SOILS AND BETWEEN MEANS OF YEARS

In Table 4 are recorded the results of an analysis of variance of the expressed plant juice data for 1932 and 1933. By this analysis we are able to segregate the variance due to differences in soils and to the differences in seasons and measure the effect of these factors on the concentration of phosphorous and potassium in the expressed plant juice. This analysis of variance embodies the data from the plats on Lebanon, Oswego, and Putnam soils in 1932 and 1933.

A comparison of the mean square attributed to the variance between the means of soils and the mean square of the error (within classes) shows a large difference which may be regarded as highly significant. This means that the phosphorous and the potassium concentrations in the plant juice differ significantly with the different soils upon which the plants were grown and that soil type is an important factor in determining the concentration of these elements in the plant juice. This is in agreement with the work of previous investigators (1, 2, 3, 16).

Part of the variance attributed to soil type must be regarded as due to climatic differences between the different fields. The field plats are located on different soil types as indicated and any climatic differences between these fields which would affect the general rate of growth or metabolism of the plants would be measured along with the soil differences. That this variance is probably small will be

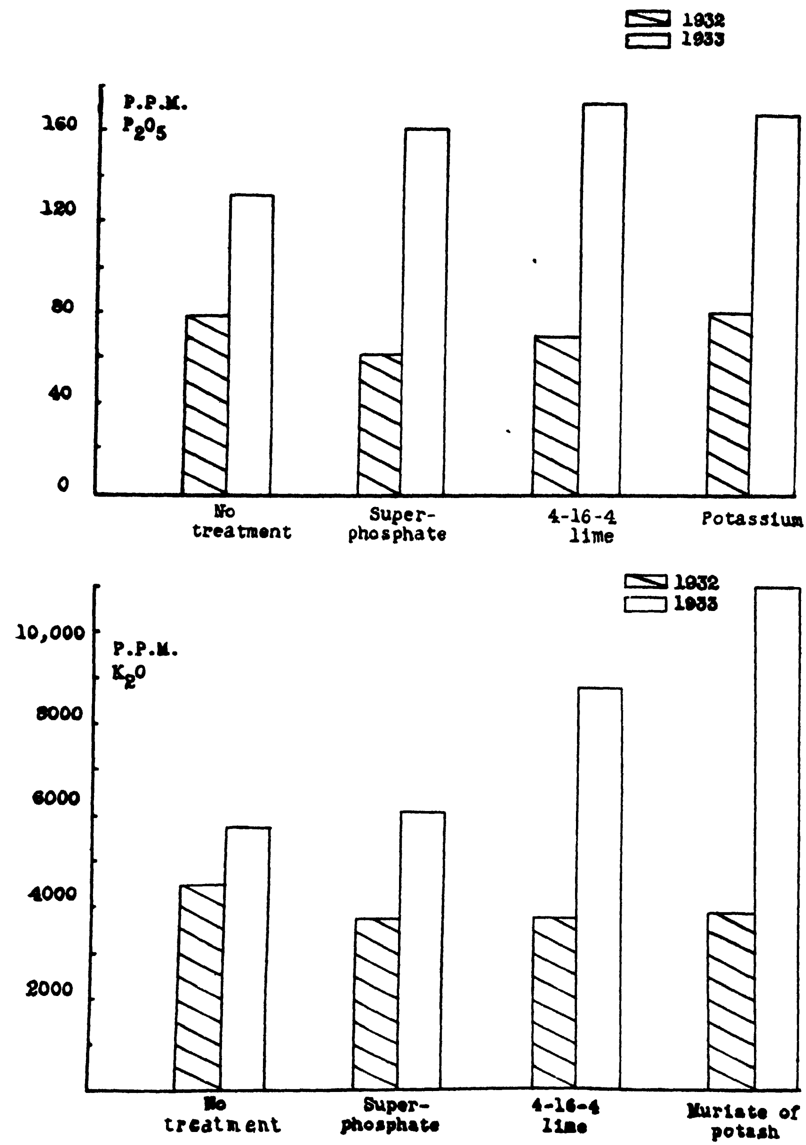

FIG. 1.—Effect of successive soil treatments on analyses of expressed plant juice of soybeans grown on Putnam silt loam, 1932 and 1933.

shown, however, by the relation of phosphorous and potassium concentrations in the plant juice in succeeding years and the relation of plant juice analyses to soil analyses.

"Within a soil type," the variance between means of different seasons may be measured by comparing its mean square with the

mean square of the experimental error (within classes). A comparison of these mean squares in Table 4 shows that climatic differences between years is a very significant factor influencing the concentrations of phosphorous and potassium in the plant juice of soybeans. Gilbert,

TABLE 4.– *Analysis of variance of phosphorous and potassium concentrations in expressed plant juice of soybeans, 1932 and 1933.**

Source of variation	Degrees freedom		Sum of squares		Mean square	
	P	K	P	K	P	K
Total	42	11	7.24	79.4931	——	——
Variance within classes (experimental error)	37	6	.80	3.1356	.022	.5225
Variance between:						
Means of soils	2	2	2.12	26.3802	1.06	13.1901
Means of seasons	1	1	2.48	39.5321	2.48	39.5321
Interaction	2	2	1.84	10.4458	.92	5.2229

*Decimal points were moved two places to the left for calculations of P and three places to the left for calculations of K.

McLean, and Adams (6) observed that any limiting condition, such as unfavorable weather conditions, which would affect the metabolism of the plant would be reflected in the plant juice analyses. During the growing season in 1932 the total rainfall was 9.31 inches and in 1933, 2.88 inches. This explains the higher concentrations of potassium in the juice the second season.

RELATION OF PLANT JUICE ANALYSES IN SUCCEEDING YEARS TO SOIL ANALYSES AND TO YIELD

By an analysis of variance we have found that the concentrations of phosphates and potassium in the plant juice of soybeans varies significantly "between soils" and "between years." In the data analyzed, the variance between years was more pronounced than the variance between soils. If we are to use comparative plant juice analyses as an indicator of the nutrient needs of plants growing on different soil types as has been suggested by several investigators (1, 3, 15, 16, 2, 11), we should determine if the relation between soils is constant when we also have a large variance due to years. Otherwise the effect of climate might outweigh the effect of soils in the plant juice when comparing results of different years.

In Fig. 2 are shown the relations of the concentrations of phosphorous and potassium in plant juice from plants grown on Oswego and Lebanon soil types in succeeding years and the corresponding relation to soil analyses. We see that in both seasons the plant juice of soybeans grown on the Oswego soil has a higher concentration of phosphates than the plant juice of soybeans grown on the Lebanon soil and that a soil analysis shows the Oswego soil also to be higher in available phosphorous than the Lebanon soil. With the potassium the reverse is true, the plant juice from soybeans grown on the Leb-

anon soil having the highest concentration for both seasons, and the Lebanon soil also having the highest concentration of available potassium.

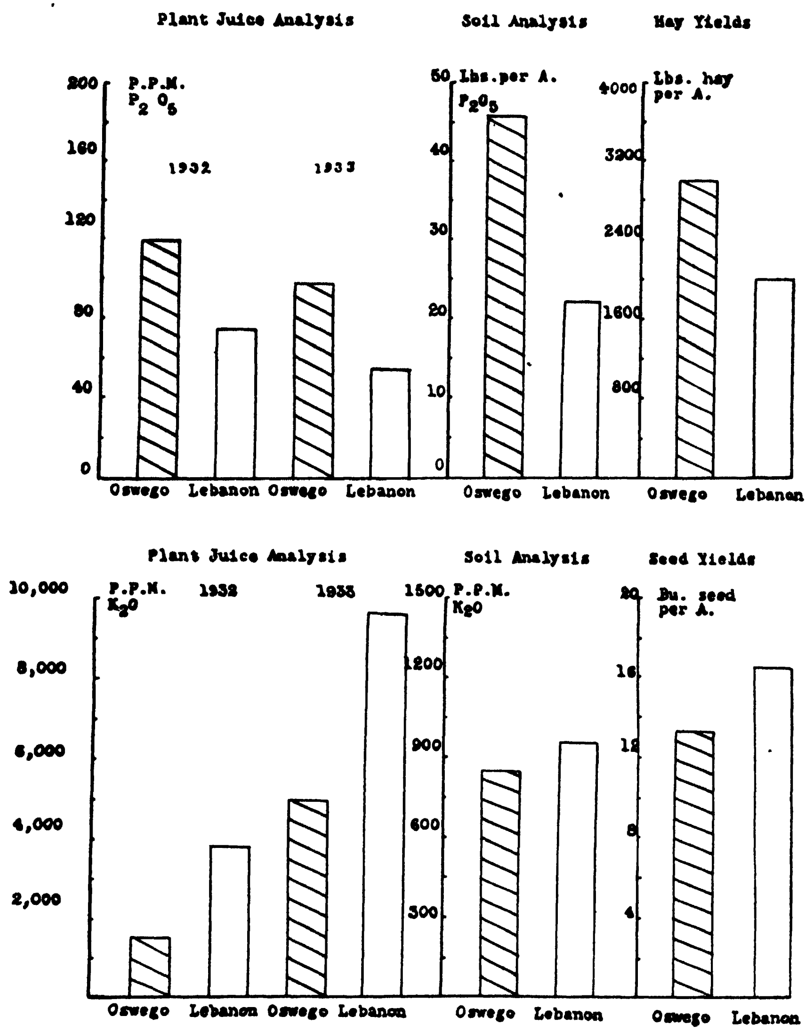

FIG. 2.—Relation of plant juice analyses to soil analyses and to yield on Oswego and Lebanon silt loam.

If plant juice analyses are to be used as an indicator of the fertilizer needs of plants growing on different soils, they should also be correlated to yield (2, 5, 6, 12, 16). This relation is shown in Fig. 2. Here there is an indication that a correlation may exist between the phosphate analysis of plant juices and hay yields, and between the potassium analyses of plant juice and seed yields of soybeans on these

soil types. This will be further analyzed and discussed under an analysis of co-variance.

CO-VARIANCE OF PLANT JUICE ANALYSES AND YIELD

The results of analyses of co-variance (17) applied to the concentrations of phosphorous and potassium in the plant juice and the yields of soybeans grown on Oswego and Lebanon soil types are given in Table 5.

TABLE 5.—*Analysis of co-variance of correlation coefficients of yields of hay and seed to concentrations of phosphorous and potassium in the expressed plant juice of soybeans grown on Oswego and Lebanon soil types.*

Source of variance	Degrees of freedom	Correlation coefficient	Regression coefficient	Odds
Hay Yields to Phosphorous				
Between soils (within treatments and varieties)	9	.742	.85	216:1
Within soils (between treatments, within varieties)	15	—.520	—1.10	66:1
Seed Yields to Potassium				
Between soils	7	.423	.081	6.4:1
Within soils	13	.460	.484	24:1

The correlation coefficient of the phosphorous concentration in plant juice and the hay yield between means of soils is .742 with a regression coefficient of yield on concentration of phosphorous of .85. This means that an increase of 1 p.p.m. of P_2O_5 in the concentration of phosphorous in the plant juice of plants on the Oswego soil over those on the Lebanon soil will be accompanied with a corresponding increase in yield of hay on the Oswego soil of 0.85 pound per acre. Within the soils there is a negative correlation of —.520 and a negative regression coefficient of yield on concentration of phosphorous of —1.10. This means that an increase of 1 p.p.m. of P_2O_5 in the phosphorous concentration of the plant juice from any plat on the Oswego or Lebanon soils will be accompanied by a decrease of yield on that plat of 1.10 pounds of hay per acre.

A reasonable interpretation of these results may be made. The concentrations of phosphorous and potassium in the plant juice represent an accumulation of these mineral elements. In a comparison of plants grown on soils low and high in nutrient elements, we would expect an increase in the concentration of mineral elements in the plant juice (9) with an increase of these elements in the soil as well as a corresponding increase in yield. This is the relation found above "between the means" of the Oswego and Lebanon soils. "Within soils" the hay yields tend to decrease with increases in the phosphorous content of the plant juice. Any condition which limits the rate of metabolism of the plants will cause an accumulation of the mineral elements in the juice (6). The negative correlation coefficient indicates the limiting factor in this case to be other than the supply of

available phosphates. When this limiting factor affects the metabolism of the plant, the yield will be limited and the phosphorous will accumulate in the juice. This accounts for the negative regression of yield on phosphorous concentration

The correlation coefficient of potassium concentration in plant juice and seed yields "between means of soils" is .423 with a regression coefficient of .081 bushel for each increase in potassium concentration of 1 p.p.m. of K_2O. This means that an increase of the potassium concentration of 1 p.p.m. of K_2O will be accompanied by a corresponding increase in yield of 0.081 bushel between the means of the two soil types. "Within the soils" the correlation coefficient is .460 with a regression coefficient of .484 bushel for each increase in potassium concentration in the plant juice of 1 p.p.m. of K_2O. The "odds" indicate that the correlation of hay yields and phosphorous concentrations may be regarded as significant, while the correlation of seed yields to potassium concentrations could not be so regarded. These correlations illustrate the variety of factors which affect and the limitations involved in setting up a laboratory method of measuring plant juice concentrations to determine the nutrient needs of plants

ESTABLISHMENT OF CRITICAL CONCENTRATIONS FOR PLANT JUICE ANALYSES

Certain investigators (5, 12) have suggested the use of critical concentrations of nitrates, phosphorous, and potassium to be maintained in the plant juice as indicators of nutrient needs of plants. The results presented in this paper, i.e., the relation of plant juice analyses on different soils in succeeding years, relation to soil analyses, and the correlation to hay and seed yields, suggest that plant juice analyses may serve as an indicator of the nutrient needs of plants on different soils. It is doubtful, however, if critical concentrations of the mineral elements in the plant juice may be set up, as has been suggested, to indicate the relative supply of these minerals in the soil. The variance in plant juice analysis due to fertilizer treatments, the variance due to different soil types, and the significantly large variance due to seasonal factors makes the establishment of critical concentrations very problematical.

SUMMARY

No significant differences could be distinguished through an analysis of variance in the concentrations of nitrates, phosphorous, and potassium in the expressed plant juice of Morse and Virginia varieties of soybeans. Moderate fertilizer treatments had no significant effect on these concentrations the first season. In the second season, where the fertilizer treatments were repeated, relations between the treatments and phosphorous and potassium concentrations were found.

Soil type and climatic differences due to seasons were both important factors in determining the concentrations of phosphorous and potassium in the plant juice. The variance due to season was larger than the variance due to soils. The phosphorous and potassium con-

centrations in the plant juice in succeeding seasons held the same relation between Oswego and Lebanon soils and were related to the concentration of these elements in the soil.

Correlations were calculated between the concentrations of phosphorous in the plant juice and the yields of hay and the concentrations of potassium in the plant juice and yields of seed. An analysis of variance and co-variance applied to the data shows the correlation coefficients and the regression of yield on concentrations of phosphorous and potassium in the plant juice.

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GENETIC RELATIONS OF THREE GENES FOR ANTHER COLOR IN COTTON[1]

G. N. STROMAN[2]

THE large number of chromosomes, 26, of the New World cottons should produce many series of genes for certain characters of the cotton plant. The present paper presents interrelations of three genes for anther color found in a natural cross of an Upland type of cotton, *Gossypium hirsutum*, with a Peruvian type, *G. barbadense*.

REVIEW OF LITERATURE

Balls (1)[3] studied anther color and obtained from an F_2 of an Upland-Egyptian cross a 1:2:1 ratio of yellow, intermediate, and buff. Kearney (5) obtained a similar result from the same type of cross but stated that the F_2 had a bimodal frequency. McLendon (6) studied anther color in an Upland-Sea Island cross but came to no definite conclusions as to number of genes involved.

Harland (3) in several crosses of New World cottons, including crosses of Upland-Upland and Upland-Peruvian, studied pollen color (the same as anther color) and concluded that there was one basic gene for yellow and white pollen which he called *P*. In this study pollen color was divided into nine different grades from dark yellow to white. However, in some of the F_2's of the crosses the segregation into two or more widely different colors was very distinct. In some of the crosses the segregation was not so pronounced. Also, there was some evidence of an intensifier gene, *Q*, which caused the yellow to be of a deeper color. Harland (4) gives a summary of genetic work done on cotton.

MATERIALS AND METHODS

The material from which these studies were made came from a hybrid plant which originated at one of the government stations about 1924. The seed of this plant was given to the writer and was planted in 1929 under the cotton breeding No. 179.

The segregation of yellow and white (or cream) was very distinct in the families referred to below. However, yellow included the pale yellows, but the distinction of yellow or pale yellow from cream or white was very clear. Throughout this treatment yellow when spoken of includes the pale yellow, and white includes the cream. In reality the white anthers in most cases are cream.

The parentage of No. 179 is not definitely known, but several government cotton men who saw it growing were very positive in saying that it was an Egyptian-Upland cross or *G. barbadense* x *G. hirsutum*. The progeny of this plant segregated for nearly all the characters of the cotton plant, but none that was noted was inherited in a simple manner.

In 1929, 1930, and 1931 the flowers of the families and progenies reported herein were tied with a string before they opened. The large numbers of plants self-pollinated in 1930 and 1931 made it impossible to self-pollinate all flowers, for in

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[3]Figures in parenthesis refer to "Literature Cited," p. 215.

the usual course of the procedure some were overlooked. However, it is known that only a small percentage was left open, and of course these in only a small percentage of cases would be accidentally crossed. Transfer of pollen from one flower to another would occur only by means of insects.

The goodness of fit method, along with Fisher's (2) X^2 tables, was used to determine the significance of the deviations, observed from expected, of the several types of ratios.

THE HYPOTHESIS

The data seem to show the presence of three genes. Two of these genes are for yellow color and the third is an inhibitor of either one of the others when they are not present together. The two genes for yellow color will be referred to as *P* and *B* and the inhibitor as *I*.

The data will be discussed from the standpoint of types of ratios and their proportion to show that the above hypothesis does fit the results obtained. The F_3 segregation of the yellow-anthered parents should show six types of F_2 genotypes. The ratios of such genotypes should be 10 pure yellow; 8, 3 yellow: 1 white; 4, 15:1's; 8, 13:3's; 4, 9:7's; and 8, 42:22's. From white parents there should be in addition to the pure white progenies, two types of progenies, one giving 3 white: 1 yellow and another type giving 13 white: 3 yellow.

THE DATA

The progeny of the parent plant, family 179, segregated into 91 yellows and 41 white anthers. This is a deviation of only 4 to fit a 42 : 22 ratio. The 42: 22 ratio is according to the hypothesis of two genes for yellow color accompanied by an inhibitor gene as stated above. In the initial year the whites were in part called pale yellow. The following year these were called cream. The yellows were separated into two grades, yellow and pale yellow; but the difference between the yellow, including pale yellow, and the so-called whites or creams, was very distinct.

The segregation the following year (F_3) of the individual progenies is found in Table 1. The totals of the segregating progenies from yellow-anthered parents are as follows: The 42 yellow: 22 white ratio is 179:89; the 3 yellow: 1 white ratio, 78:26; the 13:3 ratio, 33:8; the 9:7 ratio, 68:45; and the 15:1 ratio, 62:5. The largest deviation of observed to expected occurs in the 9:7 ratio, but even here the P = .30 to .50. There may be some doubt of separating 3:1 progenies from 13:3 progenies or of 15 : 1's and the pure yellow progenies even though their total observed fit their respective ratios. Throwing together the kinds of progenies just mentioned the ratio of genotypes should be 14, pure yellow and 15 : 1's; 16, 3 : 1's; and 13 : 3's; 4, 9 : 7's; 8, 42 : 22's, a total of 42 genotypes. The observed gave 8 : 6 : 4 : 5, a total of 23 progenies. The goodness of fit of calculated to observed gave for these genotypes a P = .30 to .50.

This genotypic test is in line with the hypothesis. In this test the pure yellows and the 15 yellow to 1 white progenies are thrown together, owing to the fact that there are small numbers in the progenies and natural crossing in the field might naturally give numbers similar to a 15 : 1 ratio. The 3 : 1 and 13 : 3 ratio progenies are

totaled together for the same reason. However, the P calculated on the ratio of progenies with all the ratios separated was nearly as large as that shown.

TABLE 1.—*Segregation as to anther color of the 179 family*

Plant No.	Anther color		Total	Family No.	Ratio	
	Yellow	White			Yellow	White
			From Yellow Parents			
36*	28	10	38	34	3	1
2	24	7	31	35	3	1
4	25	16	41	36	9	7
5	37	18	55	37	42	22
9	32	17	49	41	42	22
10	12	8	20	42	9	7
11	25	6	31	43	13	3
15	41	20	61	46	42	22
18	2	7	9	49	1	3
19	24	16	40	50	9	7
20	16	1	17	51	15	1
23	8	0	8	54	Pure?	
29	17	1	18	57	15	1
27	38	1	39	58	Pure	—
35	31	0	31	62	Pure	—
49	7	1	8	65	15	1†
54	10	1	11	67	15	1
56	11	4	15	68	3	1
58	52	26	78	69	42	22
58B	8	0	8	70	Pure	—
59	7	5	12	71	9	7
79	8	0	8	75	Pure?	
99	17	8	25	79	42	22
112	15	0	15	82	Pure?	—
132	8	2	10	85	13	3
76	19	2	21	92	15	1
			From White Parents			
1	15	5	20	31	3	1
31	0	117	117	33	—	Pure
8	3	19	22	39	—	Pure
7	3	33	36	40	—	Pure
16	2	51	53	47		Pure
17	0	13	13	48		Pure
22	1	70	71	53	—	Pure
26	0	8	8	56	—	--
28	2	48	50	59		Pure
30	7	76	83	60	—	Pure?
37	4	46	50	63	—	Pure
42	3	42	45	64	—	Pure
64	10	15	25	72	1	3?
110	7	49	56	81	3	13
118	0	27	27	83	—	Pure
125	2	16	18	84	1	3‡

*No record of parent color
†Not included in genotypic test
‡Next year's progeny segregated giving dominant white, 3 whites : 1 yellow

To verify the hypothesis further, evidence of the plantings in 1931 will be presented. These plantings included family No 69, from 179-58,

which gave a 42 : 22 ratio of yellow to white anthers. This is a duplication of the 179 family, and the data are shown in Table 2. The totals in the several segregating ratios are as follows:

	Yellow	White	Total	Progeny numbers and P
Ratio	42	22	64	69–3, 11, 20, 24, 37, 39
Observed	719	349	1,068	P = .20 to .30
Ratio	3	1	4	69–1, 2, 4, 42, 59, 66, 78, 80
Observed	538	199	737	P = .20 to .30
Ratio	9	7	16	
Observed	150	88	238	69–5, 8
Calculated	134	104	238	P = .02 to .05
Ratio	15	1	16	
Observed	101	7	108	69–17, 19
Calculated	101.25	6.75	108	
Ratio	13	3	16	
Observed	412	95	507	69–25, 27, 30, 54, 68
Calculated	412	95	507	

The fit of calculated to observed is good on all types of ratios except possibly the 9 : 7 ratio. However, the genotypic test where the ratio of progenies should be 14, pure yellow and 15 : 1's : 8, 3 : 1's : 4, 9 : 7's : 8, 13 : 3's : and 8, 42 : 22's gave for the observed, respectively, 8 : 8 : 2 : 5 : 6 which is a total of 29 progenies. A P = .70 to .80 shows good agreement of calculated to observed. It will be noted that only the progenies of parents with yellow anthers are summarized, because the progenies of white-anthered parents were discriminated against by reason of the fact that yellow color was believed to be dominant to white. However, it is seen in Tables 1 and 2 that some of the progenies of plants with white anthers did segregate. The 3 white to 1 yellow and the 13 white to 3 yellow are according to the hypothesis. There are several that apparently give a 15 white to 1 yellow ratio, which is not according to the hypothesis and could have been caused by accidental crossing in the field. It has been noted that the self-pollination of these progenies was not 100%. The writer is of the opinion that this is the cause of the aparently 15 white : 1 yellow ratio. However, it might be attributable to a modifying gene not accounted for here.

In Table 2, plant No. 11 was recorded as of a cream color, but it is the writer's opinion that this was a mistake and probably caused by recording the color from a flower before the pollen was ripe. Another questionable progeny will be found in Table 1, plant No. 18, which gave a 3 white : 1 yellow segregation.

FURTHER EVIDENCE

The 1931 planting consisted also of the progeny of plant No. 19 of family 179 under genetic family No. 50, plant No. 36 of family 179 under family No. 34, and plant No. 125 of family 179 under family No. 84. Table 1 shows the segregation of the parent progenies. The 50 family

gave a 9 yellow 7 white ratio; the 34 family, a 3 yellow : 1 white ratio; and the 84 family the reverse of the latter, giving a 3 white : 1 yellow ratio.

TABLE 2 —*Segregation of anther color of the progenies, the color of the parent plant, and family number indication of the genotype in the 69 family.*

Plant No	Anther color		Total	Ratio	
	Yellow	White		Yellow	White
		From Yellow Parents			
1	71	27	98	3	1
2	141	49	190	3	1
3	55	30	85	42	22
4	23	8	31	3	1
5	29	17	46	9	7
8	121	71	192	9	7
11	144	76	220	42	22
17	43	3	46	15	1
19	58	4	62	15	1
20	199	93	292	42	22
22	230	2	232	Pure	—
24	82	35	117	42	22
25	140	36	176	13	3
27	128	25	153	13	3
30	47	11	58	13	3
32	39	2	41	Pure	—
36	73	2	75	Pure	—
37	122	59	181	42	22
39	117	56	173	42	22
42	116	47	163	3	1
45	101	2	103	Pure	—
54.	68	16	84	13	3
59	43	15	58	3	1
66	33	12	45	3	1
68	29	7	36	13	3
70	14	0	14	15.1	Pure yellow?
73.	17	2	19	Pure?	—
78	68	24	92	3	1
80	43	17	60	3	1
		From White Parents			
14	42	224	266	3	13
16	0	263	263	—	Pure
21	12	129	141	—	Pure
26	2	201	203	—	Pure
28	3	87	90	—	Pure
33	3	71	74	—	Pure
50	7	84	91	—	Pure
64	10	32	42	1	3
71	1	31	32	—	Pure
75	3	93	96	—	Pure

Tables 3 and 4 give the detailed data on the progenies of these families. According to the hypothesis, two types of ratio should be found from the progenies of family 50, i.e , 9 . 7 and 3 . 1; and the calculated to observed on the segregating progenies show the proportion to be excellent The theoretical ratio of genotypes should be 1

pure yellow to 4, 9 : 7 progenies to 4, 3 : 1 progenies. There were found a total of 1 : 5 : 8, respectively, which gave of calculated to observed a P equaling .50 to .70.

In Table 4 is found a summary of the data of family 34, the calculated to observed giving a P = .20 to .30. The ratio of homozygotes to heterozygotes of 1 : 2 is realized in 5 homozygotes (all yellow) and 9 heterozygotes (3 yellow : 1 white). Seed from only yellow-anthered plants were planted in this family.

TABLE 3.—*Segregation of anther color in family 50 whose parent gave 9:7 ratio of yellow to white anther.*

Plant No.	Anther color		Total	Ratio	
	Yellow	White		Yellow	White
		From Yellow Parents			
5	31	19	50	9	7
6	15	12	27	9	7
8	22	7	29	3	1
10	14	8	22	9	7
13	17	14	31	9	7
17	29	9	38	3	1
21	39	25	64	9	7
26	36	11	47	3	1
29	59	21	80	3	1
30	52	23	75	3	1
33	17	7	24	3	1
36	6	0	6	Pure	–
37	19	7	26	3	1
39	46	9	55	3	1
		From White Parents			
3	1	65	66	–	Pure
7	0	70	70	–	Pure
12	0	22	22		Pure
15	2	35	37	–	Pure?
18	3	43	46	–	Pure?
22	0	9	9	–	Pure

The summary of data on the 84 family is also shown at the bottom of Table 4. In this family a reversal of dominance occurred. The total of 3 white . 1 yellow anther progenies is shown. The fit is practically perfect. However, from Table 4 it is seen that the supposedly pure whites give some yellow anthers, which may be attributed to accidental cross-pollination or else might be accounted for by modifying genes. There is some excess of homozygotes to heterozygotes. Still, when plants Nos 7 and 10 are eliminated owing to the fact that No. 7 had a yellow-anthered parent and No. 10 was probably a natural hybrid, the ratio of homozygotes to heterozygotes is good. According to the hypothesis, there is another type of ratio, the 13 white : 3 yellow, that has not so far been discussed. In Tables 1 and 2, progenies 179–110 and 69–14 gave such a ratio. Both of these had white-anthered parents and gave a total of 273 white to 49 yellow. This is a fair approximation of a 13 : 3 ratio, there being a deviation of 11 between calculated and observed, and P exceeds the 1% point.

TABLE 4.—*Segregation of yellow and white anther color in two families, family 34 where one dominant factor for yellow is found and in family 84, a factor pair making white dominant.*

Plant No	Anther color		Total	Ratio	
	Yellow	White		Yellow	White
	Family 34, Color of Parents was Yellow				
5	14	7	21	3	1
6	50	14	64	3	1
8	25	15	40	3	1
9	20	0	20	Pure	–
12	60	17	77	3	1
14	12	4	16	3	1
15	51	21	72	3	1
20	26	14	40	3	1
22	16	0	16	Pure	–
27	69	0	69	Pure	–
31	49	24	73	3	1
32	30	3	33	Pure	-
34	108	35	143	3	1
Total 3:1 progenies	395	146	541	P = .20 to .30	
	Family 84, Color of Parents was White				
1	0	154	154		Pure
2	3	10	13	1	3
5	10	33	43	1	3
6	12	135	147	–	Pure?
7	4	2	6*	?	–
8	7	69	76	–	Pure?
10	11	1	12	?	
12	17	59	76	1	3
17	1	13	14		Pure?
18	5	17	22	1	3
19	4	56	60	–	Pure?
20	24	52	76	1	3
Total 1:3 progenies	59	171	230	–	
Calculated 1 to 3..	57.5	172.5	230	–	–

*Color of parent yellow.

The interrelations of the three factors *P*, *B*, and *I* as given here and as shown by the several different types of ratios in three generations should not be an unusual example in cotton. There are comparatively few interrelations reported in cotton, but on account of the large number of pairs of chromosomes in the New World cotton, and their relatively small size, such interrelations should be very common.

SUMMARY

Data are presented on anther color in cotton which seem to verify the hypothesis that there are two basic genes, *P* and *B*, for yellow and white anthers, with an additional gene, *I*, which when present inhibits either *P* or *B* when either is alone. The interrelations of these

three genes are shown by the several ratios of yellow to white, namely, 42 : 22, 3 : 1, 9 : 7, 13 : 3, 15 : 1, 1 : 3, and 3 : 13.

Such ratios should not be uncommon in cotton, owing to the large number of pairs of chromosomes found in the New World cottons.

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A 25-YEAR FIELD COMPARISON OF HIGH MAGNESIUM AND HIGH CALCIUM LIMES[1]

T. E. ODLAND AND H. C. KNOBLAUCH[2]

THIS experiment was started at the Rhode Island Station in 1909 for the purpose of comparing the two kinds of lime, high magnesium and high calcium, in both the limestone and hydrate forms. Reports on various phases of this experiment have been published from time to time. It is the purpose of this paper to report the yields of crops obtained during the last 13-year period and to summarize briefly the results to date on soil reaction.

The interest in the relative merits of dolomitic and high calcium limes has been greatly stimulated in the last few years since it has been found that many soils along the Atlantic Coast are becoming deficient in magnesium (2, 5)[3].

A number of experiments have been reported where magnesium and calcium limes have been compared with respect to relative availability and neutralizing value. These comparisons have generally been for a much shorter period than those here reported. The Rhode Island experiment differs from most other long-time field comparisons in that all the forms are applied at a chemically equivalent neutralizing basis as determined by acid titration in the laboratory. The MgO content multiplied by 1.4 gives the theoretical CaO equivalent.

MacIntire (7) reached the conclusion that over a period of 4 years in lysimeter tests there was little difference between the availability of hydrated lime, limestone, and dolomite when the limestones were between 100 and 200 mesh in fineness and the soil was of good fixing capacity.

Metzger (9) in comparing hydrated lime, "plant lime" (a precipitated calcium carbonate), high calcium carbonate and dolomitic limestone in a laboratory study found their rate of reaction with the soil was in the order named. The author concludes, however, that it is doubtful whether any practical significance may be attributed to the differences in rates of reaction among the materials tested.

Lipman, *et al.* (6), in comparing magnesium and calcium limestones at three different rates of application over a 15-year period, found that the two forms of lime gave results that were quite similar. With the 4,000-pound application of magnesium limestone there were a few cases of crop injury. For the entire period there was a slight difference in favor of the magnesium limestone. There was some evidence to show that the magnesium limestone favored nitrogen fixation somewhat more than the calcium limestone.

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[3]Figures in parenthesis refer to "Literature Cited," p. 221.

DESCRIPTION OF EXPERIMENT

The arrangement of plats and treatments in this experiment have been described in detail by Hartwell (4). It consists of five plats each 2/15 acre in area. Four of these plats have been limed as indicated (Table 1) and one plat (82) has been left unlimed. The liming materials have been applied at a rate to give the same CaO equivalent on each plat with the exception that the south half of plat 74 has received 50% extra. Lime has been applied at six different times during the course of the experiment, namely, in 1909, 1914, 1916, 1921, 1924, and 1925. The total amount applied is approximately equal to 15 tons of limestone per acre. At the present time all limed plats show approximately a neutral reaction (Table 2).

Hartwell (4), in reporting the experiment in 1921, came to the conclusion that practically the same results may be expected with these different forms of lime provided the limestones are fine enough to pass through an 80-mesh screen and all forms are applied at the same neutralizing equivalent rate.

TABLE 1.—*Lime materials applied in pounds per acre to plats over a 25-year period on liming experiment.*

Plat No.	Kind of lime	Total pounds over 25-year period		
		CaO content	MgO content	CaO equivalent
74N.....	Calcium hydrate	13,918	874	15,142
76......	Magnesium limestone	7,887	5,396	15,441
78......	Calcium limestone	14,448	596	15,282
80	Magnesium hydrate	7,699	5,453	15,333
82.	None	0	0	0

TABLE 2.—*Soil reaction and lime requirement of plats in liming experiment.**

Plat No.	Kind of lime	Year									
		1921		1924		1928		1932		1934	
		pH	L.R.†	pH	L.R.	pH	L.R.	pH	L.R.	pH	L.R.
74N	Calcium hydrate	6.3	1,530	5.8	1,580	7.7	405	7.4	306	6.4	693
76...	Magnesium limestone	6.2	1,800	5.7	2,120	7.3	477	7.2	396	6.8	693
87...	Calcium limestone	6.4	1,530	5.7	1,670	7.5	396	7.4	324	6.7	450
80...	Magnesium hydrate	6.7	1,440	5.9	1,400	7.6	360	7.3	369	6.8	495
82...	None	4.9	3,690	4.5	4,400	4.6	3,708	5.0	3,501	4.3	3,717

*The authors are indebted to the Department of Chemistry for pH and lime requirement determinations. Lime requirement in pounds per acre according to modified Jones method.
†L.R. = Lime requirement.

Mather (8), summarizing the results in 1922, found that crop yields had been approximately the same on all four limed plats. The effect on the soil reaction had been about the same. Burgess (1), in

reviewing these results up to 1924, concluded that the limestones were apparently a little less permanent in their effect on soil acidity than the hydrates. He also found evidence that the magnesium limestone plat had produced a little larger average yield than had the other plats.

The forms and analyses of the lime materials used prior to 1921 have been reported in Rhode Island Bulletin 186. The limestones used in 1921, 1924, and 1925 were more finely ground than those used previously. In 1921, 72% of the calcium limestone and 60% of the magnesium limestone passed through a 200-mesh screen. In 1924 and 1925 the percentages passing through a 200-mesh screen were 78 and 85, respectively, for the two limestones.

The kind of fertilizer used has varied from year to year depending upon the crop grown. For cultivated crops it has approximated 1,500 pounds per acre of a 4 8 8 and for hay crops about 1,000 pounds of a 2 10 10. The nitrogen has been supplied in a mixture of nitrate of soda and sulfate of ammonia, the phosphoric acid chiefly in double superphosphate, and the potash in sulfate of potash-magnesia. The latter has been used in order to guard against possible magnesium deficiency in available nutrients. The double superphosphate was used in order to reduce to a minimum the amount of calcium supplied in the fertilizer

After the last lime application in 1925, a pronounced manganese deficiency developed on all four plats receiving lime. After the trouble had been diagnosed, manganese sulfate was applied on the west half of each plat while the east half was left without manganese for comparison. The yields here presented are based on the part receiving manganese. With a number of crops very striking results have been obtained by the use of manganese on these plats (3).

No definite rotation of crops has been followed. The general plan has been to grow two years of cultivated crops followed by two years of grass. The yields of different crops are presented on a percentage basis in Table 3. This method was chosen in order that the relative yields of the different crops might be more easily compared. The actual computed yield per acre is given for the plat taken as representative of 100%. In some years when a number of crops have been included the area devoted to each crop has been rather small and therefore the yields should not be over emphasized.

Since the south half of plat 74 has received more lime than the other plats only the north half of this plat has been used for comparison where there has been an apparent difference in yield between the two halves. Beets and cauliflower in 1925, also corn and beans in 1926, have been left out of this comparison due to very poor or otherwise abnormal yields in these two years. Other crops grown during these two years are included.

In order to get a figure to represent the relative yield of each plat over the period under consideration the percentage yields were averaged. In a similar way the average percentage yields for the previous period, 1910 to 1921, were also averaged and are presented for comparison.

As may be seen in the table the average percentage yields for the period 1922 to 1934 were 82, 90, 89, 89, and 51 for plats 74, 76, 78, 80, and 82, respectively. For the previous period they were 86, 92, 90, 91, and 58, respectively.

TABLE 3.—*Percentage yields of crops on liming experiment.*

Year	Crop	Unit	Yield taken as 100%	Plat No.				
				74	76	78	80	82
1922.....	Rape	Tons	25.92	96	80	97	100	75
	Vetch	Tons	6.75	83	88	100	81	77
	Onions	Bu.	332	71	100	70	57	15
	Pumpkins	Tons	9.80	83	100	86	97	81
	Buckwheat	Bu.	46.50	84	74	100	84	97
	Parsnips	Bu.	644	92	100	95	87	60
	Leek	Cwt.	292	91	91	100	89	0
1923 ...	Hay	Tons	1.24	81	100	97	100	60
1924. ...	Hay	Tons	3.68	100	88	90	73	56
1925	Spinach	Bu.	2,000	82	100	63	76	0
	Oats	Tons	4.07	91	82	66	80	100
	Cabbage	Barrels	347	88	85	86	100	23
	Peppers	Bu.	556	100	87	70	68	46
	Beans	Bu.	23.00	83	96	83	100	65
1926	Lettuce	Cwt.	289	92	100	99	81	10
	Onions	Bu.	717	70	100	66	80	1
	Mangels	Tons	37.95	75	91	100	81	11
1927	Hay (green)	Tons	13.42	87	84	100	99	69
1928. .	Hay (dry)	Tons	4.54	100	99	89	95	64
1929 ..	Sweet corn	Lbs.	10,091	87	97	92	92	100
1930 ...	Hay	Tons	2.64	71	89	93	100	36
1931 ..	Spinach	Bu.	3,136	59	100	98	84	2
	Beets	Bu.	195	71	55	100	74	7
	Potatoes	Bu.	172	53	79	100	93	98
	Mangels	Tons	25.00	72	73	78	100	51
	Tomatoes	Bu.	690	42	83	87	96	100
1932.....	Potatoes	Bu.	447	87	100	97	97	97
	Spinach	Bu.	776	82	77	79	100	0
	Tomatoes	Bu.	737	82	85	94	100	90
1933.....	Hay	Tons	1.94	94	100	87	82	52
1934.....	Hay	Tons	2.95	94	99	90	100	40
Average per cent, 1922–1934.............				82	90	89	89	51
Average per cent, 1910–1921.............				86	92	90	91	58

In both of these periods the unlimed plat, 82, has averaged about 40% less in yield than the limed ones. Among the limed plats, 76, 78, and 80, have been about on a par, while 74 has been a little lower in

each period. Records over a 15-year period previous to 1909 when this experiment was started and during which time all these plats were treated uniformly showed that plat 74 was as productive at the beginning of the experiment as the other plats.

DISCUSSION

The results obtained in the comparison of liming materials have shown that when these different forms are applied in amounts to supply the same neutralizing equivalent their effects on the soil reaction as measured by pH determinations have been equal over a 25-year period. In other words the theoretical value, MgO having 1.4 times the neutralizing value of CaO on a weight basis, has been verified under field conditions over a comparatively long period of years.

These tests moreover show that these four liming materials have had practically equal lasting qualities in the soil. The yields of crops following the application of the lime have also indicated that as far as rapidity of action goes there has been but little difference between the hydrate and limestone forms when the latter have been finely ground.

The yields of crops over the entire period of years also indicate that in general there has been little difference in these materials on net results in crops produced. The possible exception is high calcium hydrate which has the lowest average yield.

SUMMARY AND CONCLUSIONS

High calcium lime in both the hydrate and carbonate forms has been compared in field tests over a 25-year period with the same forms of magnesium lime. The lime materials have been applied at the same calculated neutralizing equivalent per acre.

The liming materials have been added at six different times during the experiment. The amount added approximates the equivalent of 15 tons per acre of limestone. This has brought the plats to a neutral reaction.

Both general farm crops and market-garden crops have been included. The same fertilizing materials have been used on all plats. Magnesium was supplied in the fertilizer in order to eliminate this as a factor from a nutritional standpoint as far as possible.

Manganese deficiency became evident on a number of crops after the soil had reached a neutral reaction.

Applied on the basis of equal neutralizing value there has been no appreciable difference between the different forms of lime with respect to their effect upon the soil acidity as measured by the hydrogen-ion concentration.

The average yields of all crops over the entire period calculated on a percentage basis were practically the same for the two forms of limestone and magnesium hydrate. The plat receiving calcium hydrate has averaged about 8% less in yield over this period.

From the data it may be concluded that these four forms of lime will give approximately equal results over a period of years when applied on a chemically equivalent basis if magnesium is not a factor from the nutritional standpoint.

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SIMPLE AND RAPID METHODS FOR ASCERTAINING THE EXISTING STRUCTURAL STABILITY OF SOIL AGGREGATES[1]

George John Bouyoucos[2]

THE finer portion of the soil and especially the colloidal fraction tends to become dispersed, to take up much more water, and to swell under one set of conditions in nature. In this physical condition the soil is regarded to be structurally unstable. Under another set of conditions the soil tends to be flocculated, coagulated, cemented, contracted, and to absorb less water. In this physical condition the soil is considered as being structurally stable. The factors that tend to produce these unstable and stable structural conditions are many, but chief among them are chemical composition of the soil colloids, application of certain fertilizers, the presence of certain native salts, and leaching.

The problem now is to devise methods which are capable of ascertaining which soils have a stable and which an unstable aggregate structure, and to measure, on a comparative basis, the degree of instability. At present, there seem to be no methods for making such determination.

In measuring the ultimate structure of soils (1)[3], the effect of various chemical agents on the rate of slaking of soils (2), and the effect of salts on the moisture equivalent and on the concentration of the soil solution (3), it was strikingly evident that of all the chemical agents employed potassium chloride and sodium hydroxide or sodium silicate had the most outstanding influence on the structure of soils. The potassium chloride tended to cause the greatest volume contraction and the greatest decrease in moisture content, while the sodium hydroxide or sodium silicate tended to produce the greatest dispersion, swelling, and increase in water content. Somewhat similar observations have been made by other investigators who have studied the effects of salts or exchangeable cations on soils or soil colloids (5, 6, 7, 8, 9).

It was at once suggested that advantage might be taken of the striking effect that KCl has upon soils in causing them to contract and in decreasing their water-holding power, to ascertain which soils possess a stable and which an unstable aggregate structure, and to measure the range of instability. It was reasoned that soils that were dispersed either as a result of leaching, or as a result of the presence of some chemical agent, and therefore possessing an unstable aggregate structure, would coagulate, flocculate, contract, and their water-holding power decrease when treated with KCl solution. Contrariwise, soils that were already flocculated, contracted and consequently in a stable structural condition, either as a result of chemi-

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[3]Figures in parenthesis refer to "Literature Cited," p. 227.

cal composition or of the influence of some chemical agent, would not show any or much physical change under the KCl treatment.

It is the object of this paper, therefore, to present two simple methods and the results obtained by them for ascertaining the existing aggregate structural stability of soils.

METHODS AND PROCEDURE

The methods adopted and employed for ascertaining the existing structural stability of soils by means of the KCl effects are (a) the moisture equivalent and (b) the volume on settling. These two diverse methods tend to check and supplement each other. The moisture equivalent was determined by the suction method (4) which is simple and rapid. It consisted of filling 2 small Büchner funnels 5 cm in diameter and 2½ cm in depth with air-dry soil that had passed through a 2-mm sieve. Care was taken to compact the soil by tapping gently the lower end of the funnels against the table. The filled funnels were placed in empty beakers and then one beaker was filled to the top with distilled water and the second with normal KCl solution. The soils were allowed to soak for about 24 hours or less and their moisture equivalent determined.

The volume on settling was determined by filling two 50-cc cylinders to the 40 cc mark with distilled water and with normal KCl solution, respectively. To each cylinder was added 15 grams of air-dry soil of the same stock that was used in the moisture equivalent determinations. After the soil had soaked for about half an hour it was stirred gently with an iron rod. The soil was first gently loosened by gradually working the rod to the bottom of the cylinder and then it was stirred by moving the rod in a forward and backward circular motion 20 times. This was repeated for each soil two or three times at intervals of about half an hour. The soil was then allowed to stand and settle for 24 hours and its settled volume recorded.

This mode of stirring allowed the soil to slake into its natural ultimate structure (1), to settle in a normal way, and to afford an easy outlet for the air to escape. It appears to be distinctly preferable to the shaking method wherein the palm of the hand is placed on the mouth of the cylinder and the soil is vigorously shaken. This latter method possesses at least two distinct disadvantages. First, in the case of the heavy clays which are very sticky and swell, it is almost impossible to loosen their particles or aggregates from the column formed, by shaking. Second, when the soil is shaken, upon settling, the particles and aggregates divide themselves according to size, whereas this does not happen when the stirring is done with a rod as described above.

With practically every soil the settled volume would become constant within 24 hours. With most soils, and especially those treated with KCl, the volume would become constant in a few hours. The liquid column above the soil column would be clear.

All experiments were conducted at room temperature. Changes of temperature caused no errors in the results because the tests for any one soil were run at the same time.

EXPERIMENTAL RESULTS

In Tables 1, 2, and 3, are presented the experimental results obtained on the structural stability of soils as revealed by their settling volume and moisture equivalent when treated with KCl solution

and when using water as a check. For each soil is also given its clay content as determined by the hydrometer method. From the results obtained the soils examined may be divided into three general classes in respect to the existing structural stability of their aggregates.

TABLE 1.—*Soils with aggregates of stable structure.*

Soils and treatments	Moisture equivalent, %	Settled volume, cc	Clay content 0.005–000 mm, %
Bladen loam 0–8 inches:			24.0
Water	24.3	14.0	
KCl	24.2	14.0	
Cecil clay loam 1–8 inches:			33.0
Water	19.8	13.0	
KCl	19.7	13.0	
Colbert clay 0–6 inches:			56.5
Water	29.9	15.5	
KCl	29.9	15.5	
Colbert clay 18 inches:			73.0
Water	47.0	19.0	
KCl	47.0	19.0	
Hagerstown silty clay loam 6–12 inches:			80.0
Water	33.7	17.0	
KCl	33.6	17.0	
Decatur clay 30 inches:			54.0
Water	29.7	17.0	
KCl	29.7	17.0	
Davidson clay loam 0–5 inches:			
Water	27.2	15.0	
KCl	27.1	15.0	
Nipe clay:			41.0
Water	30.0	13.4	
KCl	29.8	13.3	
Clay loam:			54.0
Water	35.2	18.0	
KCl	35.3	18.0	
Miami silt loam, subsoil:			46.0
Water	15.1	21.3	
KCl	15.0	20.8	
Irredel loam 10–20 inches:			74.1
Water	36.1	18.0	
KCl	35.1	18.0	

Class 1 comprises soils with a stable structure, class 2 those with unstable structure, and class 3 soils with moderately unstable structure.

Table 1 contains class 1 soils which reveal a stable existing aggregate structure. In these soils the KCl treatment produces no change in their settling volume and moisture equivalent from the order ob-

tained with water treatment. It is probably significant to note that lateritic soils are in this class and that these soils contain a low silica : iron-alumina ratio.

TABLE 2.—*Soils with aggregates of unstable structure.*

Soils and treatments	Moisture equivalent, %	Settled volume, cc	Clay content 0.005–000 mm, %
McKenzie clay:			76.0
Water	70.2	26.0	
KCl	43.0	19.0	
Marengo clay:			96.0
Water	71.4	25.0	
KCl	54.3	19.5	
Ontonagon clay C:			72.5
Water	42.4	21.7	
KCl	37.9	18.6	
Alkali soil:			67.0
Water	39.7	17.0	
KCl	33.2	15.0	
Lake Charles, surface:			42.0
Water	34.2	17.9	
KCl	27.2	16.3	
Miles fine sandy loam, surface:			38.5
Water	24.8	14.8	
KCl	20.7	13.0	
Buchner silty clay loam, surface:			39.5
Water	34.6	18.2	
KCl	29.2	16.2	
Grundy silty loam, surface:			38.5
Water	34.4	16.0	
KCl	28.2	14.3	
Montsuma loam 0–22 inches:			37.0
Water	30.8	15.5	
KCl	26.5	14.2	
Stockton clay adobe, surface:			73.9
Water	46.9	19.1	
KCl	37.2	16.0	
Fargo clay 6 inches:			60.0
Water	43.8	19.6	
KCl	37.0	18.0	
Lufkin clay 10–16 inches:			90.0
Water	66.1	22.5	
KCl	59.0	20.2	

Table 2 represents class 2 soils which reveal an unstable existing aggregate structure. In these soils the KCl treatment tends to reduce markedly both the settling volume and the moisture equivalent.

Table 3 contains class 3 soils which show only a moderately unstable existing aggregate structure. In these soils the KCl treatment reduced the volume and moisture equivalent to only a very moderate degree.

The settled volume and moisture equivalent always ran parallel and agreed with one another in every soil tested. This agreement by two diverse methods lends greater confidence in the reliability of the results.

TABLE 3.—*Soils with aggregates of moderately unstable structure.*

Soils and treatments	Moisture equivalent, %	Settled volume, cc	Clay content 0.005–000 mm, %
Janesville silt loam, surface:			23.0
Water	25.2	14.8	
KCl	23.4	14.0	
Marion silt loam, surface:			27.0
Water	27.6	15.5	
KCl	24.3	15.1	
Clinton silt loam, surface:			31.0
Water	27.5	15.7	
KCl	25.2	15.3	
Yolo clay loam, surface:			51.0
Water	41.4	18.0	
KCl	39.4	17.0	
Susquehanna clay 24 inches:			57.0
Water	35.8	19.5	
KCl	34.6	18.0	

All the experimental data contained in Tables 1, 2, and 3 were obtained with a normal solution of KCl. Many trials were made using different concentrations of KCl. It was found that the maximum effect on the decrease in volume and water equivalent was reached at the concentration of about normal. As the concentration was decreased, both the volume and water content tended to increase, showing that concentration also exerts an effect upon them.

SUMMARY

Potassium chloride has a most pronounced effect in contracting the volume and decreasing the water-holding power of deflocculated soils.

These phenomena were utilized in studying the structural stability of soil aggregates by measuring their settled volume and moisture equivalent when treated with normal solution of KCl.

From the experimental results obtained, the soils examined group themselves into three classes in respect to their existing aggregate structural stability. Class 1 contains soils which reveal a stable existing aggregate structure. In these soils the KCl treatment produces no change in their settled volume and moisture equivalent, but they remain the same as with the water treatment.

Class 2 comprises soils which reveal an unstable existing aggregate structure. In these soils the KCl treatment tends to reduce markedly both the settled volume and moisture equivalent.

Class 3 represents soils which show only a moderately unstable existing aggregate structure. In these soils the KCl treatment reduces the volume and moisture equivalent to a varied but moderate degree.

Both the settled volume and moisture equivalent always ran parallel and agreed with one another in every soil. This fact indicates that both of these methods give reliable results.

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METHODS FOR DISTINGUISHING BETWEEN LEGUME BACTERIA AND THEIR MOST COMMON CONTAMINANT[1]

ALVIN W. HOFER[2]

A CERTAIN soil saprophyte which has commonly been confused with the legume bacteria and which was first described by Beijerinck and van Delden (1)[3] as *Bacillus radiobacter* is well known today as a frequent contaminant of legume inoculants. Lohnis (4) called the organism *Bacterium radiobacter*; but Bergey (2) has placed it in the genus *Achromobacter* because *Bacterium* is not recognized in this classification.

The transfer from *Bacillus* to *Bacterium* was certainly justified, as nearly all bacterial classifications at present reserve the former genus for spore-forming bacteria. To a writer who continues to recognize *Bacterium*, however, there is no reason for taking it out of this genus until such time as its characters are sufficiently well known to place it in some genus with other bacteria to which it seems to be related. For the purpose of this paper, therefore, it will be denoted *Bacterium radiobacter* (Beijerinck and van Delden) Löhnis.

The first suggestion as to practical methods for differentiation between *Bact. radiobacter* and the legume nodule bacteria (species of *Rhizobium*) was offered by Lohnis and Hansen (5). They found that potato slants and litmus milk were useful for this purpose. *Bact. radiobacter* produced a brown coloration of the medium, while *Rhizobium* did not. In the hands of other investigators, however, the coloration produced by certain strains of *Rhizobium* and the lack of coloration on the part of certain strains of *Bact. radiobacter* were sufficient to confuse the results in many cases so that soil bacteriologists are reluctant to use these media. Another medium, veal infusion, was proposed by Hofer and Baldwin (3) because it allowed *Bact. radiobacter* to grow well, while most of the legume bacteria did not.

The present investigation was begun with the purpose of comparing a number of media inoculated with strains of *Bact. radiobacter* procured from various laboratories throughout the world and with several species of *Rhizobium* which were obtained originally from the collection of the University of Wisconsin. The first media to be tested were Endo's medium, eosin-methylene-blue medium, and other indicator media. None of these proved suitable, but tests of veal infusion showed it to have value. Two other media were developed for the purpose, and the description of all three follows.

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[3]Figures in parenthesis refer to "Literature Cited," p. 230.

MEDIA USED

Veal broth.—Add to 1¼ pounds of lean ground veal 1,000 cc of distilled water and refrigerate over night. Strain through cheesecloth and make up to a liter. Add 10 grams of peptone and 5 grams of salt. Steam 45 minutes and filter through paper. Adjust to pH 7.8 with N/1 NaOH (10–15 cc). Steam 45 minutes and adjust to pH 7.8 or 8.0. Filter through paper, tube, and sterilize.

Moderately alkaline liquid medium.—Mannitol, 10 grams; K_2HPO_4, 0.5 gram; $MgSO_4$, 0.2 gram; NaCl, 0.1 gram; $CaCO_3$, 0.05 gram; Bacto yeast extract, 3.0 grams; distilled water, 1,000 cc; N/1 NaOH, 18 cc; and 1.6% thymol blue, 1 cc. The reaction immediately after sterilization is pH 10.0 or above.

Strongly alkaline liquid medium.—The composition of this medium is exactly the same as that of the alkaline liquid medium above, with the exception that 28 cc of N/1 NaOH are added to each liter instead of 18 cc. The reaction immediately after sterilization is pH 11.0 or above.

All cultures were incubated at 25°C. The veal infusion was allowed to remain in the incubator for 5 days, the moderately alkaline medium for 6 days, and the strongly alkaline medium for 12 days. All determinations were made in duplicate. Because of the similarity in the results obtained with the veal infusion and the moderately alkaline medium, they are reported together. Although these two media usually produced splendid results, they were not always successful in differentiating between *Bact. radiobacter* and *Rh. meliloti*, the alfalfa organism. Because of this fact, strains of the latter species were omitted from the tests.

RESULTS

In the case of the veal infusion, a total of 90 individual determinations was carried out upon cultures of the genus *Rhizobium* in three tests. Growth developed in only two of these determinations. In the same tests, 127 individual determinations were carried out upon 50 available cultures of *Bact. radiobacter*, all of which produced growth in every instance. When inoculated into the moderately alkaline medium, *Bact. radiobacter* in 282 individual determinations during six tests produced growth without exception. *Rhizobium* cultures used during these six tests totalled 138, but none of these produced growth.

Because these two media were not suitable for distinguishing between *Bact. radiobacter* and *Rh. meliloti*, the strongly alkaline medium was devised. Three tests of this medium included 147 inoculations of *Bact. radiobacter*; 45 of *Rh. meliloti*, and 63 of other cross-inoculation groups of *Rhizobium*. After incubation, it was found that every culture of *Bact. radiobacter* had developed, as shown by the turbidity of the medium. With *Rhizobium*, growth occurred only in two cultures, both of which were for the inoculation of alfalfa.

This is by far the best record obtained with any of the media tested, and for this reason, it is felt that the strongly alkaline medium holds promise as a means of differentiating between the bacteria named. The only objection seems to be the length of the incubation period, but even this is shorter than that of cultures inoculated into milk or potato which may require up to 4 weeks.

There are certain precautions, however, which must be followed in the use of this medium. One is that typical forms of the organisms should be used rather than atypical, "yellow", or dissociated forms.

Another is that less than the stated amount of sodium hydroxide, rather than more, is necessary, because the amounts used in these experiments are near the alkaline end of the range within which the cultures will grow. Furthermore, since marked changes in pH sometimes occur in the incubator or refrigerator and since these changes reduce the sharpness of the distinction between the two groups of bacteria, the medium should contain thymol blue to show when these reaction changes occur.

Because an incubation period of 12 days at 25°C was found most favorable for the strongly alkaline medium and one of 6 days for the moderately alkaline medium, it is suggested that this time and temperature be used. This allows development of those strains of *Bact. radiobacter* which do not grow so rapidly as the rest. Also, agar must be omitted, because *Rhizobium* cultures are more likely to grow in the solid medium.

In conclusion, this investigation suggests that new tests for differentiating between *Bact. radiobacter* and various species of *Rhizobium* will be more likely to consist of the imposition of severe growth conditions upon the bacteria than in the selection of one from the other by such means as are used to distinguish the members of the colon-typhoid group. It is possible that other unfavorable growth conditions can be set up which would inhibit *Rhizobium* while still allowing growth of the more hardy *Bact. radiobacter*.

SUMMARY

Tests of veal infusion and of a moderately alkaline medium showed these media to be accurate in distinguishing between *Bacterium radiobacter* and strains of *Rhizobium* other than *Rh. meliloti*. These media did not require so long a time as milk and potato and the reactions were more clear cut. However, since they did not distinguish between *Bact. radiobacter* and *Rh. meliloti*, a strongly alkaline medium (about pH 11 0) was prepared for the purpose. This required more time for incubation than the other media, but it proved to be much more reliable. Because it distinguished between *Bact. radiobacter* and the more common species of *Rhizobium* there was no necessity for making an exception of the alfalfa group.

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INDIGENOUS SPECIES OF RHIZOBIUM IN THE ARNOT FOREST[1]

J. K. Wilson[2]

It has been noted in recent years that black locust (*Robinia Pseudo-Acacia* L.) is gradually spreading over certain areas of New York State. An examination of the roots of both seedlings and large trees shows that they bear nodules. Whether the organism that produces these nodules is indigenous to the various soils or whether it is spread over the countryside by one or more agents such as dust particles carried by the wind, flowing water, or transfer by animals from a center of infection is uncertain. Also, one or more species of nodulated Trifolium can be found on nearly all cultivated land in New York State, and in a few locations certain species of Medicago and Vicia can be found growing indigenously. The successful growth of such plants depends largely on the presence of the homologous root nodule bacteria in the soil.

Areas that have never been cultivated and have been occupied continuously, and almost if not exclusively, by non-leguminous vegetation are excellent places from which to obtain samples for a study of the indigenous presence of certain species of Rhizobium. Such an area is found in the Arnot Forest.

The Arnot Forest was a tract of virgin timber until 1870 to 1885. Logging occurred during this period. Approximately one-half of the tract was burned over between 1885 and 1928. It came into the possession of Cornell University in 1928. It consists of 1,883 acres and is located in southeastern Schuyler County, 18 miles southwest of Ithaca, N. Y. The topography is that of a deeply dissected plateau, ranging in elevation from 1,170 to 1,900 feet above sea level.

The only indications that leguminous plants have grown on the soils in this area were a few alsike clover plants along one of the stream banks and a few hog peanut plants at one edge of the forest. It is doubtful whether species of Medicago or of Vicia ever grew in the forest area Also, so far as can be ascertained, no locust trees ever grew on this tract of land. A careful survey shows a few locust trees at a distance of 1 to 2 miles on two sides of the forest. These apparently represent encroachments toward the forest area. Only a few acres have ever been cleared and cultivated. These facts, together with the observation that rather large quantities of organic matter as forest litter are deposited on the surface of the soil every year, make it a very attractive place from which to obtain samples of soil for a study of the indigenous presence of certain species of the root nodule bacteria.

SOILS USED

Since Cornell University received this forest land the major soil types have been located and mapped. This made it possible to obtain samples of soil from the

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major soil types which have been tentatively correlated and thus to add materially to the permanent value of the findings. The soils have been weathered from weakly glaciated till and are strongly influenced by the local shales and sandstone.

The samples which were used in this study were taken from the surface 3½ to 4 inches of soil. A place was selected from which to obtain the samples which looked as though it had never been disturbed. After the plant debris was removed the soil was loosened by means of a stiff spatula and then placed in previously sterilized pint mason jars. Before the spatula was used again it was wetted with 95% alcohol and the alcohol burned off. Twenty-six of the samples came from areas that so far as could be determined have never been cultivated, while three of the samples came from areas that sometime or other may have been cultivated. These samples of soil were collected July 27, 1934, and were obtained from those soil types which are recorded in Table 1. They represent seven soil series. The accompanying topographical map (Fig. 1) shows the location in the forest from which each sample came.

METHODS

In order to determine the presence or absence of the root nodule bacteria in the collected samples of soil it was necessary to grow leguminous plants on the soil and at the same time avoid contamination. To do this and to obtain suitable conditions for nodulation, 1-liter erlenmeyer flasks were used. In each flask was placed 500 grams of a dry sandy soil as a medium in which to grow the plants. The flasks were plugged and sterilized. A 20-gram portion of the sample of soil from the forest was weighed on a piece of clean paper and was then poured into the flask after the plug was temporarily removed. The sample was then mixed with the sandy soil in the flask by shaking the flask. Subsequently the soil was seeded.

The samples were examined for four species of the root nodule bacteria. Seeds of black locust (*R. Pseudo-Acacia* L.) were covered with concentrated sulfuric acid for 5 hours. They were then thrown into a large volume of water and most of the acid washed off. After this they were immersed in a solution of calcium hypochlorite for 10 to 15 minutes. The agent was then drained off and the seed rinsed once or twice in distilled water and well drained. While the seeds were still wet with the hypochlorite solution they were distributed on the surface of the soil in the erlenmeyer flasks. As soon as the seeds on the surface of the soil appeared to have dried sufficiently so that the chlorine from the calcium hypochlorite had disappeared, the soil medium in the erlenmeyer flasks received enough water to make conditions suitable for bacterial growth and seed germination. The water contained 0.05% saccharose and 0.01% K_2HPO_4. Seeds of vetch and red clover were covered with the acid for about 30 minutes, washed, and then immersed in the calcium hypochlorite solution. Seeds of alfalfa were immersed in the hypochlorite solution only.

In order to hasten germination and to produce uniformly good seedlings so that nodulation would readily occur in case the homologous root nodule bacteria were present, the seeds on the surface of the soil in the flasks were covered with some of the sandy soil. This was accomplished by dribbling some of the sterile soil through a funnel into the flasks thus covering the exposed seeds. The plantlets were 22 days old when they were examined for nodules. During this growing period when it was judged necessary, sterile water was blown from a wash bottle into the flasks after temporarily removing the cotton plugs. This was done in order to maintain suitable conditions for plant growth. It was necessary only once.

RESULTS

It is evident from the data which are presented in Table 1 that there were no root nodule bacteria for alfalfa or for vetch in a 20-gram portion of any of the 29 samples of soil. Bacteria capable of nodula-

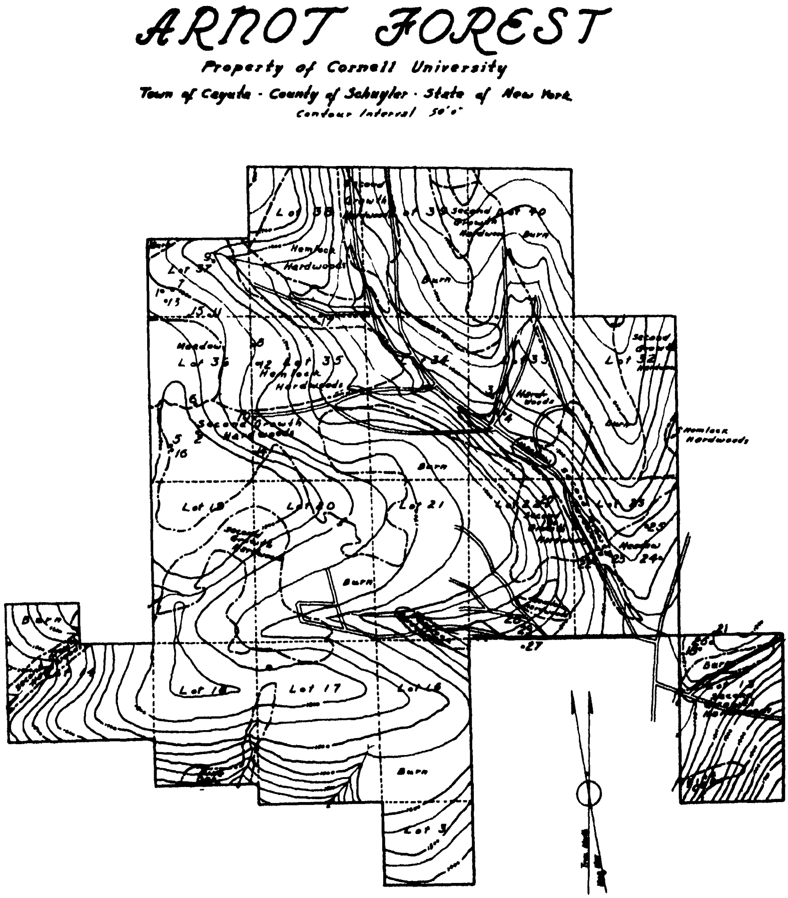

FIG. 1.—Map showing locations by serial numbers where samples were collected.

ting red clover were present in three soils. One of these was a Lordstown gravelly silt loam and the other two were Volusia soils. It is evident also that bacteria capable of nodulating locust seedlings were present in 5 of the 29 samples. They were present in four Volusia soils and in one Otisville gravelly silt loam. Homologous bacteria for red clover and locust were found together in two samples of the Volusia series.

To supplement the data presented in Table 1, flasks were seeded with the four legumes and inoculated with pure cultures of the homol-

TABLE 1 —*Recording the presence or absence of four species of Rhizobium in samples of soil from the Arnot Forest*

Lot No	Sample No	Elevation, feet	Forest type*	Soil (tentative correlation)†		Litter‡	pH	Presence or absence of root nodule bacteria capable of producing nodules on §			
								Locust	Red clover	Alfalfa	Vetch
37	1	1,805	HH	Volusia	s l	Grain mull	6 0	+	—	—	—
33	4	1,360	2nd	Volusia	s c l	Twin mull	5 4	—	—	—	—
35	10	1,730	2nd	Volusia	s l	Twin mull	5 5	—	—	—	—
23	22	1,250	B	Volusia	s c l	Twin mull	5 5	—	—	—	—
23	25	1,275	M	Volusia	s l	Meadow	4 9	—	—	—	—
38	17	1,480	2nd	Volusia	s c l (g s p)	Twin mull	5 7	+	+	—	—
22	27	1,350	B	Volusia	s l (g s p)	Meadow	5 2	+	+	—	—
22	29	1,355	B	Volusia	s c l (g s p)	Grain mull	5 3	+	—	—	—
36	2	1,850	HH	Lordstown	g s l	Detritus mull	4 7	—	—	—	—
36	5	1,920	2nd	Lordstown	f s l	Root duff	5 2	—	—	—	—
36	6	1 910	2nd	Lordstown	g s l	Root duff	5 4	—	+	—	—
35	8	1,820	HH	Lordstown	g s l	Root duff	5 0	—	—	—	—
37	11	1,900	HH	Lordstown	g s l	Root duff	4 7	—	—	—	—
35	14	1,810	2nd	Lordstown	s p	Root duff	4 5	—	—	—	—
37	13	1,850	HH	Lordstown	g s l	Root duff	5 0	—	—	—	—
37	15	1,920	HH	Lordstown	g s l	Root duff	4 7	—	—	—	—
36	16	1,970	HH	Lordstown	f s l	Root duff	4 3	—	—	—	—
22	28	1,310	B	Lordstown	g s l	Root duff	4 0	—	—	—	—
33	3	1,390	H	Mardin	g s l	Root duff	4 8	—	—	—	—
37	7	1,800	HH	Mardin	g s l	Root duff	5 0	—	—	—	—
37	9	1,665	HH	Mardin	g s l	Root duff	5 0	—	—	—	—
35	12	1,805	HH	Mardin	g s l	Root duff	4 3	—	—	—	—
13	18	1,275	B	Otisville	g s l	Grain mull	5 8	+	—	—	—
13	26	1,280	B	Otisville	g s l	Twin mull	4 9	—	—	—	—
22	19	——	H	Bath	g s l	Root duff	5 0	—	—	—	—
22	20	——	H	Bath	g s l	Root duff	4 8	—	—	—	—
13	21	1,250	B	Otisville, eroded phase		Old field	4 8	—	—	—	—
23	23	1,245	M	Canfield	g s l	Meadow	4 7	—	—	—	—
23	24	1,250	M	Canfield	g s l	Meadow	4 8	—	—	—	—

*HH = hemlock hardwood, H = hardwood, 2nd = 2nd growth hardwood, B = burn, and M = meadow
†s l = silt loam, s c l = silty clay loam, g s l = gravelly silt loam, f s l = flaggy silt loam, s p = steep phase, and g s p = grey surface phase
‡Data furnished by C H Diebold, following classification of Romell (4)

ogous root nodule bacteria. These were prepared to determine whether the conditions in the flasks were suitable for nodulation. Also, checks were provided to ascertain the reliability of the method. The results that were obtained from the supplementary tests indicated that the data were reliable and that they were suitable data from which conclusions may be drawn.

DISCUSSION

The 29 samples of soil from the Arnot Forest, representing 8 of the Volusia series, 10 of the Lordstown, 4 of the Mardin, and 3 each of the Otisville, Bath, and Canfield were examined for certain species of Rhizobia. The host plant of these species so far as could be ascertained has never grown in the forest area. This number of samples ought to be sufficient to show clearly whether Rhizobia species are indigenous in the Arnot Forest. It has been shown by Wilson (1)[3] that it is unnecessary in the case of the root nodule bacteria for Vicia and Pisium that these plants must grow on a soil before their homologous bacteria will establish themselves in the soil. If nutritional conditions are adequate and species of Rhizobia are naturally introduced they will survive as long as these conditions obtain, irrespective of whether the host has grown on the soil. If this view is tenable, then it is evident that Rhizobium for locust is indigenous in certain soil types in the Arnot Forest. This may be one reason why locust is gradually encroaching on certain areas in New York State, and may indicate that the homologous root nodule bacteria either precedes its host into new areas or that it is naturally present in certain soils. It should be pointed out, however, that the Rhizobium for locust was not indigenous in the Lordstown, the Canfield, the Mardin, or certain of the other soil series. This is taken to indicate that for this organism the nutritional conditions at the present time in these soil series are inadequate. These inadequacies either obtain for the Rhizobia of alfalfa and of vetch in all seven of the soil series and for the Rhizobium of red clover in 27 of the 29 samples of soil or these species of Rhizobia have never by chance come in contact with these soils. These unfavorable nutritional environments for the homologous bacteria species of Medicago and Vicia may explain in part why representatives of these two plant groups are not found indigenously in this forest area.

No evidence was obtained which might be regarded as furnishing a possible explanation for the presence of species of Rhi obium in one soil type and their absence from another. For this reason the data should not be taken to indicate, without further studies, that a soil of the Lordstown or Mardin series in another section of New York State would not support a certain species of Rhizobium because the organism was not found in the soil of these series in the Arnot Forest. After making a study of the relative numbers of three species of Rhizobia in Dunkirk soil, Wilson (2) concluded that no significance could be attached to the moisture content of the soil, to the season of the year when the samples were taken, or to the crop on the soil

[3]Figures in parenthesis refer to "Literature Cited," p. 236.

as bearing any relation to the ability of a soil to support certain species of this organism. It was suggested by Wilson (3) that other agents, such as the type of inorganic salts present in the soil solution and the quality of the organic matter in the soil, may be factors supporting Rhizobium in the absence of its symbiont.

It is evident from the data presented that the quantity of forest litter added to the soil from year to year is not effective in establishing and maintaining a population of certain species of Rhizobia of such magnitude that the organisms can be found in 20-gram portions of the soil. In addition the data are not extensive enough to show whether the forest type or the type of decaying litter as defined by Romell (4) bears a relation to these bacteria.

CONCLUSIONS

Soil samples were collected from seven soil series in the Arnot Forest. These were used as an inoculum for a medium in which leguminous plants were grown. The presence of nodules was the criterion of the presence in the soil of species of Rhizobium. It is concluded that the Rhizobium for black locust is indigenous in certain areas, that the Rhizobium for red clover is present in 2 of the 29 samples, and that the Rhizobia for alfalfa and for vetch were not present in any of the soil series examined.

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COMPOSITION OF BLACK LOCUST LEAF MOLD AND LEAVES AND SOME OBSERVATIONS ON THE EFFECTS OF THE BLACK LOCUST[1]

A. F. GUSTAFSON[2]

DURING April 1934 the writer's attention was attracted to the organic material on the surface of the soil under a thick stand of black locusts (*Robinia pseudoacacia* L.). These locusts are located in the town of Bath, Mason County, in central Illinois. The soil is mapped as dune sand according to the Illinois soil survey, the soil map of Mason County having been made by a field party under the direct charge of the writer. It was during this work that the author became interested in the growing of the black locust on this dune sand of which 75,443 acres is found in Mason County. This acreage constitutes 21.37% of the area of the county.

This particular locust area was started by planting sprouts about 25 years ago for the purpose of controlling the blowing of the sand. During the intervening years the size of the planting has become enlarged greatly by natural means, mainly sprouting. Fires burn over this sand area all too frequently, the most recent fire having occurred in 1931. The heat from these fires is so intense as to kill most of the locust growth above ground, consequently the present growth consists of sprouts which have come up from the live roots since the latest fire.

The surface of the sand under the locusts was covered with the remains of the locust leaves and some small twigs which had accumulated during the past 3 years. In the absence of facilities for collecting samples, a board 12 inches square was placed on the surface of the soil. It was held down by standing on it and the organic matter cut off by running a knife around the edge of the board. The leaf material was then raked away from the board, the board removed, and the organic material collected from the square foot which the board had covered. The samples were taken to Ithaca, where dry matter, loss on ignition, and total nitrogen were determined. These data are given in Table 1.

A number of points are brought out by these data. First, it is little short of crime to permit the destruction by fire of 101 pounds of nitrogen and nearly 1¼ tons of organic matter to the acre, in addition to the killing of the above-ground locust growth.

While making the soil map, as well as since then, the writer observed Kentucky bluegrass (*Poa pratensis*) well established and making good growth under black locust trees even though this bluegrass does not grow on this sand away from groups of locust trees. The growth of bluegrass in association with the black locust appears fully explained by the above data; the locust leaves supplying nitrogen and other nutrients, holding moisture, and probably helping to hold

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, New York. Received for publication January 2, 1935.

[2]Professor of Soil Technology.

down the temperature of the sand during hot periods. Second, this organic matter in conjunction with the locust trees had completely stopped sand movement by the wind. Moveover, productive soil adjacent to active sand dunes is being destroyed by a covering of sand blown over it from the dunes. Even when the dunes "move on" sufficient covering of coarse sand is left to render cultivation of what was formerly good soil impracticable.

TABLE 1.—*Composition of black locust leaf material and quantity of it to the acre.*

	Samples		
	1	2	Average
Air-dry sample (including some underlying sand), grams	97	95	96
Moisture, %	5.69	6.15	5.92
Nitrogen (air-dry basis), %	1.260	1.152	1.206
Loss on ignition, %	25.83	25.77	25.8
Weight of material over an acre (including some sand), lbs			8,695
Nitrogen per acre in material (1.282%, average, dry basis), lbs			101.47
Loss on ignition per acre, lbs			2,243

This observation suggests the use of black-locust wind breaks or solid planting of locusts on sand dunes or light sandy loams for anchoring the sand in its present position. The use of conifers interplanted with locusts might be feasible, provided the growth of the locusts is controlled so they do not over-top the conifers and prevent their making the desired growth for wind-break purposes.

Chapman[3] has shown that the effect of black locust leaves blown over among such deciduous trees as catalpa, white ash, tulip poplar, black oak, and chestnut oak is to increase their growth materially both in height and in diameter immediately adjacent to the locusts as compared with distances of 12 to 72 feet away. The same relationship precisely was found in the nitrogen content of the soil, it being 0.196% among the locusts and 0.090% at a distance of 72 feet from the locusts. As Chapman points out this difference may appear to be small, but it is equivalent to 3,900 pounds of nitrogen to the acre among the locusts and to 1,800 pounds 72 feet away, a difference of 2,100 pounds to the acre—6 inches weighing 2,000,000 pounds.

Chapman gives the nitrogen content of elm and of a mixture of elm and locust leaves throughout the season. For October 12 the nitrogen content of the elm leaves was 2.06% and that of mixed elm-locust leaves 2.46%.

The writer collected leaves from black locust trees in Ithaca on the edge of the Cornell University Campus about October 9, 1934. Owing to the shorter growing season at Ithaca as compared with Ohio, however, the stages of maturity of the leaves from these two places are not strictly comparable. The nitrogen content of the locust leaves at Ithaca was 2.33% (dry basis), which is practically the same as that

[3]CHAPMAN, ARTHUR GLENN. Report of the fourteenth annual meeting of the American Soil Survey Association. Bul. 15: 39–41. 1934.

of red clover at full bloom. Red clover cut at approximately that stage at Ithaca contained 2.34% nitrogen[4] in the first cutting as an average of ten analyses covering a decade. During the same period the second cutting had on the average 2.75% nitrogen.

Ebermayer[5] reports beech and pine as producing 2,800 pounds of dry matter to the acre as leaves and needles and 3,000 pounds of beech leaves to the acre in France.

If the black locust produces approximately this quantity of leaves, they contain about 70 pounds of nitrogen to the acre, or on the basis of a ton of locust leaves, 46.6 pounds of nitrogen to the acre. This is an important contribution of nitrogen and organic matter to the soil.

This calculation is made purely for the purpose of calling the attention of workers to the possibility of using legume trees in plantations with non-legumes. Control of the legumes will be essential owing to their rapid growth. Over-topping of non-legume trees might be avoided if these are planted in narrow belts alternated with belts of locusts.

AGRONOMIC AFFAIRS

PLAN FOR ADMINISTERING THE ANNUAL CHILEAN NITRATE AWARD FOR RESEARCH ON THE RARER ELEMENTS IN AGRICULTURE

THE Chilean Nitrate Educational Bureau is providing the sum of five thousand dollars annually as an award for research on the value of the rarer elements in agriculture. The award will be sponsored by the American Society of Agronomy.

The plan for administering the award is as follows:

1. The award shall be known as the Chilean Nitrate Award for Research on the Rarer Elements in Agriculture.

2. The purpose of the award is to stimulate research with the rarer elements in relation to economic crop production.

3. Details of administering this award shall be in the hands of a committee of six, chosen from among the members of the American Society of Agronomy and known as the Committee on the Chilean Nitrate Award for Research on the Rarer Elements in Agriculture.

4. The committee administering this award shall be appointed by the President of the Society and shall consist of two members being appointed for 3 years, two for 2 years, and two for 1 year. Vacancies created by the automatic retirement of two members each year shall be filled by the President of the Society, each incumbent being appointed for a period of 3 years. Each incoming President of the Society shall designate the Chairman of the committee for the ensuing year.

5. Awards shall be made to individuals for outstanding research on the presence of the rarer elements in plants and their rôle in crop production and plant nutrition.

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[4]Unpublished data supplied by Dr. T. L. Lyon, Agronomy Department of the Cornell University Agricultural Experiment Station.

[5]EBERMAYER, ERNEST. Phys. Chem. der Pflanz., 1: 41–44.

6. The awards are to be used by the recipients in furthering research on the rarer elements or for professional advancement.

7. The amount of each award shall be determined by the committee in each individual case.

8. In making the awards the committee shall consider:
   (a) The work accomplished, as indicated by published and unpublished data.
   (b) The interest and activity of the worker in research.

9. Any research worker in the United States or Canada shall be eligible to receive recognition.

10. The announcements of awards shall be made each year at the annual meeting of the Society.

M. J. FUNCHESS, OSWALD SCHREINER, C. F. SHAW, H. H. ZIMMERLEY, J. G. LIPMAN, R. I. THROCKMORTON, *Chairman*

Committee on the Chilean Nitrate Award for Research on the Rarer Elements in Agriculture.

The committee requests that the Chairman be advised of all applicants and nominees for the award and that copies of all published reports of research and, when possible, manuscripts of unpublished results of research be sent to him. The names of all applicants and nominees and reports on their research should be sent to the Chairman by August 15, 1935.

A BIBLIOGRAPHY ON THE RARER ELEMENTS

The Chilean Nitrate Educational Bureau announces the publication of a bibliography containing some 1,800 references on the rarer elements assembled by Dr. L. G. Willis of the North Carolina Agricultural Experiment Station.

When ready, this bibliography will be distributed without cost to all who desire copies as long as the supply lasts. Those who wish to receive copies of the bibliography should notify the Chilean Nitrate Educational Bureau at 120 Broadway, New York City.

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OBSERVATIONS ON THE WHOLE WHEAT MEAL FERMENTATION TIME TEST[1]

E. G. BAYFIELD[2]

PLANT breeders desiring to undertake quality studies early in the development of new varieties are handicapped by having but small quantities of seed available. Such quality studies are particularly necessary to the originator of new wheats. Orthodox methods for testing such wheats require several pounds of seed if regular milling and baking studies are to be undertaken. Tests for evaluating the quality of new wheats before these several pounds of seed become available have long been needed. Great interest was aroused, therefore, when Pelshenke (15)[3] and Cutler and Worzella (8) published details of their methods for testing wheat quality using small amounts of whole wheat meal.

Since their original paper, Cutler (7) and Cutler and Worzella (9) have published further results obtained through the use of their test. Based upon these results, they (9) suggest a classification of wheats based upon the "time" as an index of quality. Wilson, Markley, and Bailey (20) found no significant correlation between the time test and protein content or loaf type when working with hard spring and hard winter wheats. They experienced considerable trouble in determining the end point of the test. Wilson and Markley (21) found a positive correlation with spring wheats ground on a Wiley mill between time of dough ball disintegration and loaf volume and baking strength score. They conclude that the test has possibilities.

Markley (13), in discussing the usefulness of the test, states (referring to Minnesota wheats), "You can tell extremes, but you cannot differentiate in the median group at all." Working with Michigan-grown soft wheats, Winter and Gustafson (22) found a fair positive correlation between the time test and loaf volume, and with expansion of dough, but not with protein content of flour. They used a modified method for determining "time," although their procedure was essentially the same as that outlined by Cutler and Worzella (8). Winter

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication January 7, 1935.

[2]Associate in Agronomy (Cereal Chemist).

[3]Figures in parenthesis refer to "Literature Cited," p. 249.

and Gustafson performed the tests at a temperature of 86° F (30° C) instead of 80° F (26.7° C) which was employed by Cutler and Worzella.

Up to the present time the author has not heard of anyone in this country working with the Pelshenke (17) procedure, which is apparently being used with success in Germany. Edel (10) reports favorably on its value after applying the test to over 2,000 samples. Pelshenke (16, 18, 19) has used his method in making wheat surveys of Germany for the 1932, 1933, and 1934 crops. However, Moh and Klemt (14) are somewhat critical of the method and advise against its introduction into Germany. Klemt (12) does not believe the "Schrotgärmethode" (the time test) a good substitute for the baking test. Results obtained by the author at the Ohio Station would indicate that Pelshenke's (17) procedure might well be tried out by wheat breeders in this country. Griffiths and Cayzer (11) have found the method promising when applied to Australian wheats. The essential difference between the Pelshenke and the Cutler-Worzella methods is the difference in size of dough balls used.

In the late summer of 1934 a number of samples of wheat too small in size to mill and bake came to the author for a quality rating. It was decided to run time tests upon them using the Cutler-Worzella procedure with the exception of a minor variation in temperature of the fermentation cabinet. Some of the varieties in the group were standard sorts. Results were so unexpectedly erratic that it seemed advisable to investigate the test and study some of the possible causes of these variations. At this time it is proposed to present some of these results as a preliminary report. This seems advisable in view of the widespread need for an adequate method of treating small plant breeding samples of wheat.

SOURCE OF MATERIAL AND METHODS

The samples employed in these studies were all grown in Ohio in 1933 and 1934 and consisted of both red and white winter wheats. The 1934 material is treated in Table 1. The 1933 crop samples were residues of a part of a much larger series studied in connection with the work of the Tri-State Soft Wheat Improvement Association program (2).

Analytical data have been obtained by approved methods (1). Baking data were obtained through the use of a modified formula of the American Association of Cereal Chemists (3). Viscosity data were obtained by the use of a constant weight of flour method (5).

GRINDING THE SAMPLE

Between 60 to 65 grams of clean, sound, dry wheat were ground on a Wiley mill using the 1-mm sieve. No specific details regarding the standardizing of this make of mill have been laid down by Cutler and Worzella beyond the use of the 1-mm sieve. Rather extensive grinding tests indicated considerable variation could be produced by changing the methods of handling the mill. As a result of these tests the grinding procedure finally used was to grind the above-mentioned amount of wheat for 4 minutes at a machine speed of 700 R. P. M. The knives must have a clearance of between 0.009 to 0.010 inch. With this method a small

amount of fine branny material does not pass through the sieve. It is mixed in with the ground material and used in the test. Grinding for longer periods so that all material passed through the sieve did not produce appreciable differences in time over a range in strength as found between the "weak" American Banner and the "strong" Michikof varieties.

After grinding a sample, the mill was cleaned by the use of a small brush followed by an air blast provided by a hand-operated automobile pump equipped with a suitable rubber tubing hose. Very little loss was experienced by this procedure (about 1 gram).

TIME TEST DETERMINATION

The first tests were made according to the specifications outlined by Cutler and Worzella (9) with the exception of using a temperature of 30° C (86° F) instead of 80° F. Pelshenke (17) used a temperature of 31° to 33° C. The cabinet temperature was electrically controlled and varied less than $\pm$ 0.3° C. Humidity was maintained between 77 and 92% by circulating air over towelling partially immersed in water. Normally the humidity was about 88%. A high humidity is desirable, as drying of the top of the doughballs influences the time of disintegration. The author was privileged to receive a demonstration in the making of doughballs from Professor G. H. Cutler while at Purdue University and thereby acquired an idea of the "feel" of the dough. This "feel" is of a consistency of a rather stiff dough and it was attempted to have all the doughballs of this consistency. Separate lots of meal were weighed individually for each doughball.

As will be shown later, the 10-gram doughballs, as specified by Cutler and Worzella, gave erratic results due to *some* samples sticking to the sides of the beaker. Thereafter only 5 grams of meal, as used by Pelshenke (17), were used. With these 5-gram doughballs only 2.75 cc of yeast solution (10 grams Fleischmann bakers' yeast in 100 cc distilled water) were used. The specified (8) 150-cc low form beakers (approximately 5.4 cm diameter) and 80 cc of water were used. Before using, the yeast solution was allowed to stand in the cabinet at 30° C for about 30 minutes. The "time" was determined by the interval found to exist between time of placing the doughball in the beaker and its disintegration. This latter occurred when the first detached piece of dough hit the beaker bottom. An extremely small piece falling was not counted as having any significance. The entire procedure is empirical and constant attention is required in the observing of the smallest details.

To ensure the elimination of the personal element it was found advisable to perform the tests in duplicate on two successive days and to take the average of three "times." If agreement was not obtained by running four doughballs a third pair was run on the third day's run and so on. If a very short "time" wheat was being run (30 minutes or less), agreement between checks had to be within 3 minutes. For the strongest red winter samples a maximum disagreement of not over 7 minutes was permitted without re-checking.

EXPERIMENTAL RESULTS AND DISCUSSION

In carrying out the tests in connection with standardizing the Wiley mill it was found that the personal element entered into the test very largely. The operations of stirring the meal and yeast solution together in the beaker with the stirring rod, duration and method of kneading of the dough in the palm of the hand, and finally, the time

and method of rolling the ball between the hands before immersing in water, all affected the time. Considerable effort was necessary before an assistant could duplicate results consistently with the author. In this respect the time test is as open to criticism as the baking test.

Finally, with these difficulties under control the series of wheat in Table 1 was run, using the 10-gram doughballs. The samples had been stored in the laboratory and had thoroughly dried out before being ground into meal. Observation of the tests indicated a definite difference between the behavior of the Trumbull and Fulhio red wheat samples from the rest which were of the weak white types. In the case of the former the doughballs became inflated, rose to the surface of the water, and then flattened out and adhered to the beaker on all sides. Fermentation gradually slackened with gas escaping through the upper surface of the mass. The depth of the mass became less and less. After this the dough was practically "dead," but did not break down due to the support received from the beaker walls. Finally, due no doubt to the action of proteolytic enzymes and the hydrolytic action of the distilled water upon the gluten, a part or all of the bottom of the fermented mass fell to the bottom of the beaker.

TABLE 1.—*Strength of wheat varieties using 10- and 5-gram doughballs, 1934 crop samples, Wood County, Ohio.*

	Trumbull*	Fulhio*	American Banner†	Gold Coin†	Honor†	Cornell 254A1 101-19†
Sample No.	2516	2517	2518	2519	2520	2521
Crude protein, %‡	13.3	12.7	12.8	11.5	11.5	12.0
Moisture in meal, %	8.1	8.5	8.0	8.6	8.2	8.5
Time test, using 10 grams meal:						
Replicate 1, minutes	**148**§	**85**	29	27	40	28
Replicate 2, minutes	**147**	**152**	30	27	39	28
Replicate 3, minutes	**147**	**139**	29	24	39	28
Replicate 4, minutes	**146**	**132**	29	24	38	29
No. replicates required	4	8	4	6	4	4
Av., 3 closest replicates, minutes	147	43‖	29	27	39	28
Total range in time, minutes	**146–148**	39–**152**	29–30	24–29	38–40	28–29
Time test, using 5 grams meal:						
Replicate 1, minutes	57	63	33	30	45	33
Replicate 2, minutes	57	53	33	29	45	32
Replicate 3, minutes	57	56	32	31	46	33
Replicate 4, minutes	57	52	33	29	44	33
No. replicates required	4	4	4	4	4	4
Av., 3 closest replicates, minutes	57	54	33	29	45	33
Total range in time, minutes	—	52–63	32–33	29–31	44–46	32–33

*Soft red winter variety.
†Soft white winter variety.
‡Converted to 15% moisture basis.
§Bold face figures refer to samples adhering to sides of beaker.
‖Final four replications were 45, 45, 40, and 39.

In the case of Fulhio some doughballs started to break up before becoming firmly attached to the beaker and irregular "times" resulted. With the white wheat samples all of the doughballs broke up before they became attached to the beaker. In these cases the gluten was exposed continually to the ever-increasing pressure of the gas formed by the yeast until disruption of the ball occurred. This phenomena only occurred during the initial stages of the stronger wheat doughballs which were prevented from complete breakdown by the support of the beaker walls. In the latter case an entirely different factor was operating and it seems as though the results between the red and white wheat samples are not comparable. In any empirical method every effort must be made to make conditions uniform, otherwise results are not strictly comparable.

The Cutler-Worzella (9) specifications call for a proportionate reduction in beaker size, amount of water, and yeast solution if the quantity of meal is reduced. Use of these instructions with a smaller sized doughball would therefore continue the above-mentioned error due to method.

To study the relative influence of beaker size and varying amounts of water, a number of tests were run which indicated conclusively that varying the size of the beaker produced large differences in time, whereas varying the amounts of water in the beaker produced relatively small differences.

The question now arose as to whether this ability to adhere to the beaker was a varietal characteristic. While this seemed an unlikely possibility, nevertheless a series consisting of 10 varieties grown at four different Ohio locations in 1933 was run by both the 10- and 5-gram doughball methods. These samples had previously been subjected to milling and various other laboratory tests and were selected so that the influence of varying strength in the different varieties could be noted. The resulting time data, together with the results of certain other tests, are presented in Table 2. In this table the varieties are arranged in order of decreasing loaf volume according to results obtained from growing the same varieties at some 46 locations in Ohio, Indiana, and Michigan during 1932 and 1933 (4). The four samples of each variety included are arranged in order of increasing crude protein content. Each variety, therefore, has a spread in strength. Study of the table indicates a number of interesting points, as follows:

1. Using 10-gram doughballs, it is seen that all varieties, except American Banner, stick to the beaker at the higher protein levels, while with one exception "sticking" is not an interfering factor in the lowest protein level. Sticking to the beaker therefore is not a varietal characteristic but occurs in any variety provided it has sufficient strength.

2. With 10-gram doughballs, more replicates were required in order to get satisfactory checks than with 5-gram doughballs. In the intermediate strengths in the various varieties where sticking was rather a haphazard occurrence, wide ranges in time occurred between duplicates run in any day.

TABLE 2.—*Data for 10 winter wheat varieties each grown at 10 locations in Ohio, 1933 crop year.*

Sample No.	Wheat protein %	Loaf volume (regular), cc	Loaf volume (bromate), cc	Viscosity (flour) °MacM*	Whole wheat meal time test: 10 grams meal, No. tests	10 grams meal, Range,† min.	10 grams meal, Av.,† min.	5 grams meal, No. tests	5 grams meal, Range, min.	5 grams meal, Av., min.
				Red Rock						
1944	8.8	535	530	72	4	39–53	50	4	58–66	63
2054	9.9	595	550	83	6	**48–154**	**154**	5	44–52	47
2044	10.2	565	532	92	8	**58–180**	**176**	4	53–65	54
1994	13.8	615	—	—	4	**202–208**	**203**	4	96–102	101
				Fulhio						
1943	9.0	532	530	78	4	38–48	47	4	53–56	54
2053	10.0	607	557	86	6	30–38	38	5	34–39	35
2043	11.2	585	595	125	4	40–45	43	4	46–50	49
1993	13.6	682	—	—	4	**180–186**	**184**	4	64–67	65
				Trumbull						
1941	9.0	540	505	76	4	44–49	48	4	55–58	57
2051	10.9	527	550	72	6	26–99	41	4	30–35	34
2041	11.2	585	557	110	7	**41–157**	53	6	44–60	46
1991	14.0	665	—	—	6	**161–184**	**171**	4	59–75	61
				Bald Rock						
1946	9.4	557	515	73	4	**63–140**	**138**	8	53–61	57
2056	10.0	575	562	72	6	**25–115**	39	4	39–42	42
2046	11.2	580	612	113	8	**46–151**	48	4	51–59	53
1996	13.9	650	—	—	6	**153–186**	**155**	4	63–73	65
				Gladden						
2060	8.1	530	475	47	6	32–40	39	4	33–36	35
1950	8.7	577	537	66	4	45–52	50	8	25–73	58
2050	11.0	605	612	112	8	50–63	56	3	51–56	54
2000	13.6	625	—	—	8	**54–196**	**179**	4	50–55	51
				Karkov						
2058	9.2	547	510	53	4	32–36	33	4	34–38	34
1948	9.8	575	557	81	4	44–47	47	4	44–48	45
2048	11.6	590	615	122	11	**45–158**	**108**	4	48–51	49
1998	14.3	627	—	—	8	**39–185**	**158**	4	51–56	52
				Michigan Amber						
1947	8.6	535	500	58	4	50–57	51	6	57–77	59
2057	9.4	550	517	71	6	**38–185**	44	4	41–45	42
2047	11.3	595	575	106	8	**51–181**	**173**	4	60–62	62
1997	14.0	640	—	—	4	**176–218**	**181**	10	68–85	79
				Fultz						
1949	9.1	552	520	80	4	45–47	46	4	49–64	50
2059	9.6	575	540	76	4	36–42	42	5	44–50	44
2049	11.1	570	577	124	7	43–51	48	6	46–57	48
1999	13.2	632	—	—	6	**168–201**	**172**	8	66–77	72
				Nabob						
1942	8.6	530	500	58	4	45–50	49	4	44–52	50
2052	9.2	567	512	44	6	**34–120**	37	4	31–39	38
2042	11.5	620	637	149	7	**54–174**	**167**	6	60–75	61
1992	12.8	605	—	—	4	**200–226**	**204**	4	74–78	77
				American Banner						
1945	9.0	520	510	48	4	34–36	35	6	34–50	37
2055	9.5	555	485	51	4	27–30	29	6	29–39	34
2045	10.8	550	590	79	4	30–35	34	4	38–41	40
1995	12.8	610	—	—	5	38–50	49	4	46–48	46

*Viscosity given in degrees MacMichael and obtained on 20-gram weight of 15% moisture flour.
†Bold face type refer to samples which stick to sides of beaker.

3. With either size of doughball there is a general tendency for increases in "time" with increasing protein content or loaf volume.

4. With the 5-gram doughballs or with the 10-gram size with no sticking, it will be observed that some other factor is interfering with this relationship between increasing time and strength. It will be seen that the protein content and baking strength in the 2051–60 series is higher than that of the 1941–50 series, although the time is less. Is the time in the latter series being unduly prolonged due to an insufficiency of sugar being available for the yeast to act upon?

5. With a given procedure, decreasing the size of dough ball gives relatively longer times provided no sticking occurs with the larger sized balls.

STRENGTH VS. QUALITY IN NEW WHEATS

The author prefers the use of the term *strength* rather than *quality* when referring to soft wheats and the measurements obtained by either the baking or time test. A strong baking flour or a long "time" wheat may be said to possess high quality for bread production, but such a strong wheat would not necessarily be of suitable quality for many of the purposes for which soft winter wheats are used. Thus, for example, the variety Michikof possesses a strong gluten, but for the manufacture of cake flour its quality is very poor. American Banner is a weak variety but is highly prized by many mills on account of its suitable quality for their purposes.

In measuring strength in wheat by any fermentation process such as by the time or baking tests, two principal factors must be considered, first, gas-retaining, and second, gas-producing abilities of the dough. Each factor is the resultant of several others, the most important of which may be expressed diagrammatically, as follows:

Wheat or Flour Strength

Gas-retention factors	Gas-production factors
1. Protein quantity	1. Sugar content of wheat or flour
2. Protein quality	2. Maltose producing ability (diastatic activity)
3. Activity of proteolytic enzymes	
4. Amount and composition of ash constituents	

In attempting to evaluate any new variety these various factors must be considered. In studying gluten or protein *quality* the amount of protein present in the sample necessarily must be considered. Furthermore, a sufficient supply of available sugar must be present in the dough, otherwise the gluten is not able to express its true strength due to an insufficiency of gas preventing the gluten being stretched to its point of rupture. Normally, in the baking test, sugar, malt, or some diastatically active material is added to the dough to ensure an adequate gas supply.

No action is taken along these lines in the time test, reliance being placed entirely upon the natural abilities of the meal itself plus the diastatic enzymes in the yeast. Recently, Coleman, Snider, and Dixon

(6) have shown that whole wheat meals vary widely in their diastatic powers. It has already been mentioned that the time of samples 1941–50 may have been influenced by a low gas production. Until the question of gas supply in the doughball is settled it must be considered as a possible source of error in the test. Seeing that diastatic activity is very considerably influenced by growing conditions, it appears as though it may eventually prove necessary to attempt to eliminate this possible variable in the time procedure.

USE OF "TIME" IN ELIMINATING UNDESIRABLE VARIETIES

The time test was developed by plant breeders primarily for the elimination of unsuitable varieties earlier in the breeding program than is possible when milling and baking tests are used. Much valuable material easily could be discarded if errors exist in the time test procedure. Table 3 shows that some varieties might easily be discarded due to the strength of the sample being exaggerated on account of the time being unduly prolonged by support being given the dough by the sides of the beaker.

TABLE 3.—*Variety strength rating according to time.*

Test	Series No.	Time in minutes*									
		Red Rock	Fulhio	Trumbull	Bald Rock	Gladden	Kharkov	Michigan Amber	Fultz	Nabob	American Banner
10-gm.	1941 to	50	47	48	**138**	50	47	51	46	49	35
5-gm.	1950	63	54	57	57	58	45	59	50	50	37
10-gm.	2051 to	**154**	38	41	39	39	33	44	42	37	29
5-gm.	2060	47	35	34	42	35	34	42	44	38	34
10-gm.	2041 to	**176**	43	53	48	56	**108**	**173**	48	**167**	34
5-gm.	2050	54	49	46	53	54	49	62	48	61	40
10-gm.	1991 to	**203**	**184**	**171**	**155**	**179**	**158**	**181**	**172**	**204**	49
5-gm.	2000	101	65	61	65	51	52	79	72	77	46

*Bold face type indicate samples which stuck to beaker.

Bald Rock in series 1941–50 is probably the worst example of this exaggerated strength as expressed by time when using the 10-gram doughballs. If sticking of the dough mass is avoided through the use of 5-gram doughballs, the wide spread in time between samples is reduced and this advantage claimed for the test is largely lost.

Examination of the 10-gram data also indicates that the varieties Nabob and Michigan Amber are relatively stronger than they actually are when considered in connection with their actual baking strength or their performance during the past 5 years of testing at the Ohio Experiment Station. These two varieties may possess low diastatic pow-

ers, seeing that even with the 5-gram doughballs they give "times" longer on the average than their known baking strengths would warrant.

SUMMARY

The whole wheat meal fermentation time test of Cutler and Worzella was applied to two series of soft winter wheats with unsatisfactory results due to the fact that uniform conditions do not hold over the range of strength found to occur in this class of wheats. With weak samples of wheat the dough mass does not stick to the sides of the beaker, whereas with stronger samples it does, with the result that strength differences as measured by "time" are exaggerated. "Sticking" of the samples in many, but not all cases, masked any differences caused by possible diastatic activity deficiencies.

The 5-gram doughball recommended by Pelshenke gives superior results to those obtained by the larger sized doughs. Even with these smaller doughballs, however, a disturbing influence is noticeable. It is thought that this may be due to diastatic differences in samples.

Closer agreement was obtained between viscosity results, loaf volumes, and protein contents than between the "time" data and the other determinations employed as comparative measures.

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SENSITIVITY OF THE POTATO PLANT TO SOIL AERATION[1]

JOHN BUSHNELL[2]

IN a fertilizer experiment at Wooster, started by Thorne[3] in 1894, potatoes have been grown in a 3-year rotation with wheat and clover. On the well-fertilized plats the wheat and clover have yielded well, but the potato yields have been below expectation.

The soil is mainly Wooster silt loam, characterized by excellent capillarity and a well-oxidized subsoil. For general agricultural purposes it is rated as one of the best soil types of eastern Ohio.

For many years the low yields of potatoes were attributed entirely to the prevalence of insects and diseases, but even when these were more and more successfully combated by spraying and the use of certified seed, the yields still failed to come up to expectation. By 1928 it was clear that either the rotation or the fertilizer treatments were not suited to potatoes.

On nearby fields a number of different rotations were then started. It was found that satisfactory yields could be obtained by heavy applications of manure or by large crops of green manures. Also, an extensive series of special tests was conducted within the fertilizer block itself on strips originally designed as roadways but which had been continuously cropped. These roadways were divided into 54 plats, each 10 by 15 feet. On some of these plats the less common fertilizer elements were added; on others new combinations of ordinary fertilizers were applied; on others the soil reaction was altered; and on still others the physical condition was changed by addition of sand or agricultural slag. Of all these special tests, the only ones giving yields distinctly higher than the ordinary fertilizers were the ones which received the applications of sand or of slag. Evidently, the problem was one of physical condition rather than of chemical relations in the soil.

RESULTS FROM SANDED PLATS

The initial tests with sand in 1929 and 1930 were applications about an inch thick spread on after plowing and disked into the top 3 inches of soil. The increases in yield were consistent but not large. The following seasons the sand was applied both before and after plowing and was thoroughly mixed through the plowed layer. The benefits were then more conspicuous (Table 1).

The problem seemed of sufficient importance to justify analyzing it a step further. To account for the benefits from the sand, three hypotheses seemed reasonable, as follows: First, moisture might have been conserved in the subsoil, due to rapid percolation of rain through the porous surface soil, followed by slower evaporation resulting from reduced capillarity; second, the porosity of the sanded soil might

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[2]Associate Horticulturist.

[3]The maintenance of soil fertility. Ohio Agr. Exp. Sta. Bul. 381. 1924.

have proved favorable for root extension; and, third, the increased aeration itself might have been of benefit.

TABLE 1.—*Increases in potato yields from adding sand to Wooster silt loam, single plats, 10 by 15 feet, yields in bushels per acre.*

Year	Sand applied per acre, cu. ft.	Yield of potatoes		Increase due to sanding, bu.
		Check, bu.	Sanded, bu.	
1929	3,600	145	177	32
1930	3,600	144	168	24
1931	7,200	259	322	63
1932	7,200	216	290	74

RESULTS FROM AERATION BY TILE LINES

For studying aeration as an independent factor, ventilating tile lines were laid in the surface soil of an adjacent field directly under potato rows. The lines were only 60 feet long and open at both ends. Presumably, these tile lines would aerate the soil near the potato roots without appreciably conserving moisture or altering the mechanical condition of the soil.

The tile were laid, after plowing, in ditches 10 inches deep, dug by hand. Two lines were laid with ordinary 4-inch clay drain tile and two with a perforated tile, each tile having 36 small holes along one side.[4] Three check rows were prepared by digging out the ditches and then refilling without tile. No method of forcing air through the tile lines was used. Changes in temperature and barometric pressure would presumably cause some gradual movement. At times, air movement could be detected by releasing a little smoke near the lower end of the lines.

After the tile were laid and the check rows prepared, Russet Rural potatoes were planted with a machine directly over the tile and at the same depth as in the check rows. There was only about an inch of soil between the top of the tile and the bottom of the seed pieces (Fig. 1).

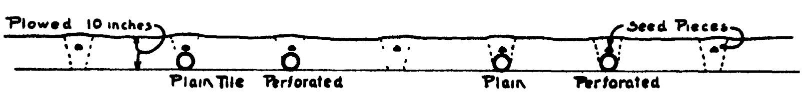

FIG. 1.—Diagram of location of tile lines. Dotted lines indicate narrow ditches dug by hand, three of which were refilled without tile; the others tiled as indicated.

The experiment was in a field which had been heavily manured in 1928 and in which soybeans had been plowed under in alternate years since. The soil, therefore, was in better condition for potatoes than any plats of the old fertilizer rotation. The experiment was conducted for two seasons, 1933 and 1934. Both seasons were very dry

[4]The perforated tile were furnished gratis by the Haviland Clay Works Company, Haviland, Ohio.

during the spring and summer but with favorable fall rains beginning about the middle of August. The rains were never heavy enough to pack the surface seriously or to cause the soil particles to coalesce in the plowed layer. Water ran out of the tile lines only twice in 1933 and five times in 1934.

The good condition of the soil and the favorable fall weather resulted in average yields from the check rows of over 300 bushels per acre both seasons, a very satisfactory yield in Ohio. The tiled rows, however, consistently outyielded the adjacent checks, and the perforated tile produced higher yields than the plain tile. The average total yields from the rows with perforated tile were over 400 bushels per acre, an increase of about 70 bushels per acre over the checks (Table 2).

TABLE 2.—*Effect of tile placed directly under potato rows, yield of 50-foot rows converted to bushels per acre.*

Row	Type of tile	Yield in 1933			Yield in 1934		
		Large*	Small	Total	Large*	Small	Total
1	None (check)	322.2	40.0	362.2	318.8	30.0	348.8
2	Plain	383.1	33.3	416.4	331.1	37.5	368.6
3	Perforated	404.8	48.4	453.2	367.5	26.5	394.0
4	None	288.4	41.9	330.3	268.0	28.3	296.3
5	Plain	341.3	37.4	378.7	324.5	33.8	358.3
6	Perforated	357.6	27.3	384.9	383.4	24.3	407.7
7	None	324.3	40.7	365.0	314.5	32.2	346.7
		Averages					
Checks, no tile		311.6	40.9	352.5	300.4	30.2	330.6
Plain		362.2	35.4	397.6	327.8	35.7	363.5
Perforated		381.2	37.9	419.1	375.5	25.4	400.9

*"Large" tubers are those more than 1⅞ inches in diameter.

The tile were removed immediately after harvest and were found to be surrounded by a network of roots. Roots were distinctly more abundant around the tile than in the main body of the soil. This fact in itself might not be particularly significant when it is remembered that the roots originated directly above the tile; nevertheless, the fact that the roots thrived in the zone which was specially aerated supports the conclusion that the benefits from the tile were actually due to increased aeration. It should be noted, incidentally, that the increases in yield from the ventilating tile were of the same magnitude as those obtained in previous seasons from sanding.

CONCLUSION

The results, as a whole, lead to the conclusion that the potato plant is peculiarly sensitive to soil aeration, and that insufficient aeration may be frequently a limiting factor in potato yields on silt loam and heavier soil types.

PLANT BREEDING OPPORTUNITIES WITH PASTURE AND MEADOW PLANTS[1]

F. D. KEIM[2]

THE improvement of pasture and meadow plants by breeding is without doubt one of the most neglected fields in the agronomic research program. No one is to blame for this because there has always been a greater demand for research with cash crops such as corn, wheat, and other grains. When experiment stations were established most of the grain fields of the present time were covered with grasses and trees. Little agrostological research was needed because there was plenty of pasture and hay. Then, too, the many species used in pastures and meadows seem to have more or less overwhelmed investigators and they scarcely knew where to begin. Such factors as the small inflorescence, the non-individualistic growth habit, the long time involved in accomplishment, and the lack of specific knowledge concerning these small-seeded grasses and legumes have played their rôle in this neglect. It is always difficult to change the old regime. It is so easy to follow in the research groove of our forefathers.

Many worth-while fertilizer, tillage, and cultural experiments have been conducted with pasture and meadow plants, but the actual plant breeding activities have been limited.

The problems brought about by the necessity of regrassing lands as an aid in programs of erosion control, land utilization, grain reduction, etc., have created a distinct need for more knowledge concerning pasture and meadow crops. This need is a challenge to the agronomic investigators of the United States that can and will be met.

Some very excellent starts in agrostological research have been made in the United States, Canada, and especially in Europe. Special note should be made of this because failure to recognize it would be inaccurate and grossly unfair, but it will be the purpose of this paper to hold rather closely to the subject of breeding opportunities and not to discuss literature.

THE ADAPTATION OF GRASSES AND LEGUMES

While the common native and cultivated grasses and legumes are found rather generally over the country as a whole, careful observation shows that most of them have a rather distinct adaptation to particular habitats. This point is quite significant. It probably means that breeding operations must be limited to comparatively small areas. For instance, facts determined by Dr. Kirk in Canada with Alpha sweet clover may not hold true for the central corn belt of the United States. The strains of clover and grasses selected by Dr. Stapleton and his co-workers at Aberystwyth probably will not suit

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our plains conditions. In fact we already have fairly good evidence that this is the case. This means, of course, that these problems should be studied under soil and climatic conditions similar to those in which the plants are to be grown. If the most is to be gained by selection and hybridization, careful preliminary habitat studies will be necessary. Each agricultural experiment station, therefore, will have its own particular problems to solve, cooperating, of course, with each other and with the U. S. Department of Agriculture on methods as well as materials. In the writer's opinion it is not good policy to delimit the investigations of specific problems to too small a group of workers, as for example a single station. Whenever real initiative is shown it should be encouraged, even though there are some overlapping efforts in areas of similar growing conditions.

The adaptation of pasture and meadow plants may be illustrated with the following chart, which shows the tentative value of the cultivated grasses and legumes when grown under the various climatic conditions of Nebraska.

*Forage plants classified with respect to climatic adaptation to the various sections of Nebraska.**

Crop	Eastern Nebraska	Central Nebraska	Western Nebraska
	Grasses		
Brome	Good	Good to fair	Fair to poor
Crested wheat	Good to fair	Good to fair (or poor)	Fair to poor
Slender wheat	Good	Good to fair	Fair to poor
Orchard	Good	Good to fair (or poor	Fair to poor (or failure)
Meadow fescue	Good	Good to fair (or poor)	Fair to poor (or failure)
Red top	Good	Fair to poor (or failure)	Failure
Kentucky bluegrass	Good	Fair to poor (or failure	Failure
Timothy	Good to fair	Fair to poor (or failure	Failure
Sudan	Good	Good	Good
	Legumes		
Alfalfa	Good	Good to fair	Fair to poor
Red clover	Good to fair	Fair to poor (or failure)	Failure
White clover	Good to fair	Fair to poor (or failure)	Failure
Alsike clover	Good to fair	Fair to poor (or failure)	Failure
White or yellow-sweet clover	Good	Good to fair	Fair
Lespedeza	Good to fair	Fair to poor	Poor

*The above classification is based upon normal upland soil.

A similar type of adaptation could be shown for the native grasses and legumes. Any student that is well acquainted with the native vegetation of the Great Plains area knows that as one goes westward

from the Missouri River the long grasses, such as the blue stems, are left behind and one gradually passes into the typical short grass country which is covered with such grasses as grama and buffalo.

The intricate relationships that exist between the available soil moisture and soil types and the botanical structure of the native vegetation are striking. Prairie hay studies[3] made in north central Nebraska showed the natural plant communities divided into five general types, as follows: (1) Wet areas, *Spartina* (slough grass) type; (2) blue stem areas, *Andropogon furcatus* and *Sorghastrum nutans* (big bluestem and Indian grass) type; (3) drier areas of the bluestems, *Sorghastrum nutans* and *Andropogon scoparius* (Indian grass and little bluestem) type; (4) transitional areas between the bluestem type and the typical successional vegetation of the sandhills, including the *Stipa-Bouteloua* (needle grass and grama grass) climax vegetation; and (5) typical successional vegetation of the sandhills. Such special conditions need to be taken into consideration in a pasture and meadow improvement program.

WHAT ARE SOME OF THE PLANT-BREEDING OPPORTUNITIES?

CULTIVATED GRASSES AND LEGUMES

Brome grass (*Bromus inermus*) without much question is one of the outstanding grasses west of the Missouri River. The seed of brome grass, however, is extremely light and chaffy. The test weight per bushel ranges from only 12 to 20 pounds. If a strain with heavier seed could be developed, it could be seeded more easily with a drill, and this would enhance materially the chances of obtaining a stand. It would also greatly facilitate the threshing operation, which at present is almost an art in itself, as anyone can testify who has ever tried it. A strain of brome grass is also needed that has less of the so-called "sod binding" habit. Selection of strains suitable for pasture and others for hay would be desirable. The time of cutting brome grass for hay is very short. If this could be corrected and a strain selected that would cure and produce a better quality of hay and a greater yield, this crop would certainly have more value as hay.

Sweet clover (*Melilotus* sp.) is another plains and corn belt plant that has proved its worth and yet has some serious weaknesses. Strains are needed that will make maximum yields of fine, leafy hay instead of the usual coarse, stemmy material produced by ordinary varieties. Will it be possible to select or breed strains that do not have the bitter taste, which do not cause bloat, that are more resistant to certain diseases, that are more acid-tolerant, and that have a smaller number of hard seeds and are less subject to shattering? The harvesting of sweet clover seed from the common tall, branching types presents many difficulties. Can the plant breeder produce a plant that will give a maximum yield of seed, hay, and pasture, and yet will not be so difficult to harvest?

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[3]KEIM, F. D., and FROLIK, A. L. Studies of prairie hay in north central Nebraska. Nebr. Agr. Res. Bul. 60. 1932.

FROLIK, A. L., and KEIM, F. D. Native vegetation in the prairie hay district of north central Nebraska. Ecol., 14 : 298–305. 1933.

Over the West, when fed alone, much difficulty is being experienced with sweet clover hay in the thinning of the blood of farm animals, which often results in serious bleeding at times of castration or dehorning. Sometimes animals actually bleed to death "in their own hides," states Dr. Van Es, animal pathologist at the Nebraska Agricultural Experiment Station. Can selections be made to do away with this trouble? Dr. Kirk, Dominion of Canada agrostologist, Dr. Brink at Wisconsin, and others have made some excellent beginnings. Studies on the subsoil moisture conditions prevailing in old alfalfa fields in the western part of the corn belt show rather clearly that uplands once in alfalfa are far less profitably cropped again to alfalfa. This fact makes sweet clover improvement all the more important.

Another unusually important temporary pasture and hay crop in the central part of the United States is sudan grass. A sudan grass is needed, however, that is somewhat more resistant to low temperature so that it can be planted earlier in the spring and the pasture season lengthened; one that ripens its seed more uniformly; and one in which there is no danger of prussic acid developing in large enough quantities to harm livestock. Possibly this last-named danger could be entirely eliminated. Strains of sudan grass selected chiefly from the standpoint of freedom from cane mixture are already being certified in a number of states. We need to go farther into the root of this trouble, however.

Lespedeza sp. could be used to better advantage if we had a desirable perennial, or if we had an annual that would make an earlier start in the spring and produce a larger tonnage per acre. With some improvement from the standpoint of hay quality and wider adaptation for both wet and dry conditions, Reed canary grass would be of much value on the low Scott and Fillmore types of soil areas over the plains. At the present time these areas are covered with weeds such as iron weeds, dock, and coreopsis.

Slender wheat, meadow fescue, and orchard grass need careful study. All of them have excellent possibilities and probably have been overlooked in western agriculture. The work of Sampson, Kirk, and others shows real possibilities especially with slender wheat grass.

More plant breeding work is being done at present with alfalfa than with any of the small-seeded grasses and legumes. It is needless to say that the accomplishments are gratifying. The results show what can be done when work is really started in earnest. There is little reason to believe that much the same improvement can be accomplished with the trifoliums and other cultivated legumes and grasses.

NATIVE GRASSES

The past summer has demonstrated rather clearly the value of the native grasses. Dried out and almost eaten out of the ground, these native grasses are beginning to show life, while the Kentucky bluegrass pastures of central and eastern Nebraska are at least 75% dead. The possibilities of selection within the various species of the native grasses were well demonstrated in some preliminary tests carried on at Nebraska this past summer. There was much evidence that there

is a great variation in plants of the same species. This variation was not confined to vegetative characters alone, but to the ability to produce good viable seed.

Blue stem (*Andropogon furcatus*) is probably one of the outstanding prairie hay grasses of the corn belt. It has at least three faults that might be corrected by plant breeding investigations. The seed is light and carries many bristles. The germination is poor. It is adapted to the more favorable soil and moisture conditions and therefore the distribution of this grass is somewhat limited. The grass if not cut before heading out makes a rather coarse, stemmy hay. It may be improved also in its stoloniferous characteristics so as to be of more value in erosion control. Much the same faults could be found with the other species of bluestem, such as *A. hallii*, *scoparius*, *saccharoides*, and *Sorghastrum nutans*.

Slough grass (*Spartina* sp.) and blue-joint grass (*Calamagrostis* sp.) are adapted to low, wet, poorly drained soils. There is an excellent chance that a finer-stemmed, softer-leafed slough grass might be selected so that the quality of hay would be improved and it would not need to be called "whip cord hay." Both of these grasses could be improved from a seed standpoint. *Calamagrostis* has a much finer leaf, but the seed is very difficult to procure. This might be greatly improved by removing it from the extremely sod-bound condition under which it usually grows.

Switch grass (*Panicum virgatum*) has one of the widest adaptations of any of the native grasses. It has excellent seeding qualities and the seed is not difficult to procure or handle. It produces a rather coarse hay, but this could no doubt be corrected by proper plant breeding methods.

The gramas and buffalo grass (*Bouteloua* sp. and *Bulbilis dactyloides*) over the drier plains area offer splendid possibilities. The side oat grama (*B. curtipendula*) is found almost everywhere. Its seed habits are such that it offers some excellent possibilities. Buffalo grass, being a dioecious plant with the pistillate flowers developing in the axils of the leaves of prostrate stems, causes seed production, and thus distribution, to be a greater problem. And yet, with some selection and proper cultural methods, it might be possible to harvest seed from this famous western grass. The work of Savage at Hays along the lines of vegetative propagation is especially noteworthy. At Lincoln, Nebr., we have found that a small 6-inch square of sod set every square yard fills in almost completely during one good, favorable growing season.

The *Agropyron* genus furnishes another group with some good possibilities. The fact that the hay feed seed division of the U. S. Dept. of Agriculture Bureau of Agricultural Economics has recognized western wheat grass (*Agropyron Smithii*) important enough to establish a set of hay grades for it indicates that it must have real value. Seed production of this grass is certainly one of its weak points. This has presented such a problem that it seldom can be found on the market. With careful selection and breeding, this deficiency can be corrected. Crested wheat grass, in spite of all the publicity it has received, is not as hardy for western Nebraska conditions as some of

the other species of *Agropyron*. Neither is it as hardy as *Bromus inermis*.

A few miscellaneous grasses adapted to special conditions should probably be mentioned here. Sand reed grass (*Calamovilfa*), blow-out grass (*Redfieldia*), and a number of drop-seed grasses (*Sporobolus* sp.) are especially adapted to extremely sandy lands. *Calamovilfa* has special stoloniferous qualities, spreading out in circles in the prairie almost like bindweed or quack grass. A few years ago in walking over a bad blow-out the writer pulled out, without breaking, a rhizome over 25 feet in length. It is extremely coarse and unpalatable both as pasture and hay. Here lies the opportunity for improvement. *Redfieldia* grows in the very loose sandy mouths of the blowouts and hence is called blowout grass. The inflorescence appears to be heavily loaded with seed. The *Sporobolus* species have very wide adaptations. *S. cryptandrus* is usually one of the first grasses to make its appearance on idle western lands that have been left to go back to grass. The writer has seen species of *Sporobolus* come up through 6 feet of blow sand. The seeds of many of these drop-seed grasses are large and smooth and should be rather easily harvested and planted.

HYBRIDIZATION

The possibility of combining the good quality of one small-seeded grass or legume with the good quality of another does not seem to be an unreasonable objective. These small-seeded plants undoubtedly present greater difficulties than the cereals, but the work at Aberystwyth, Ottawa, and in this country with timothy and alfalfa shows clearly that there are many possibilities ahead. Space does not permit a detailed discussion of hybridization. The fact that many of the grasses and legumes are cross-fertilized will present many difficulties. Real progress has been made with selfed lines of corn, and with the development of some special technic the same results can be accomplished with the pasture and meadow plants.

MISCELLANEOUS SUGGESTIONS

Three more suggestions will be offered. The first is along the line of cultural practice. Greenhouse facilities will be necessary to start selections and make the crosses. Special seeding operations, especially for the drier areas, should be taken into account. We summer plow and keep all weeds down for winter wheat production in dry-land agriculture. Why should we not do at least this much for these small-seeded grasses and legumes? There is the best of evidence at North Platte that brome grass stands are almost assured if this practice is carefully followed. This special seedbed preparation, with the use of a drill where possible, will do much to assist in making headway with plant-breeding operations.

The second suggestion has to do with man power. This work must be made one of the major divisions of the experiment station program and men must be placed in charge who have the proper agronomic and botanical training to do the job. This work must be a job and not one of the chores.

The third suggestion has to do with a more or less general condition. During the past few years soil erosion caused by both wind and water has called to our attention more than ever before that we have some serious soil problems to solve. Sodding this land with grasses and legumes and proper rotation seem to be the best remedy. In the past legumes have received much attention because of their fertilizing value. This has been good practice, but may we not have overlooked in part the importance of the soil-binding qualities of the fibrous-rooted grasses?

THE ADAPTATION OF CORN TO CLIMATE[1]

DONALD F. JONES AND ELLSWORTH HUNTINGTON[2]

RECENT investigations demand a revision of the prevalent idea that seed corn brought from a distance will not produce so abundantly as local varieties. It has been widely recognized that a change in latitude brings about a marked difference in vegetative growth and time of ripening because of the alteration in the relative length of day and night. The assumption has been that this change generally works adversely. It has also been assumed that a change in longitude, since it does not alter the length of the period of daylight, produces little effect except when it means a change to deficient summer rain. Nevertheless, the prevalent opinion throughout the principal corn-growing states has been that when seed is planted at distances of more than a few hundred miles east or west of where it was grown it will not do so well as varieties which have long been grown locally.

This widely held idea seems at first sight to be supported by practical experience. Seed from the North Atlantic states will not produce as much grain or forage in Ohio or Ontario as the best native sorts. Ohio and Ontario seed, in turn, usually does not give as good performance as the home-grown sorts in Illinois or Wisconsin. Local varieties from these latter sources, in turn, usually fail in Kansas, Nebraska, and the Dakotas, unless the season there is unusually favorable, as one of the writers well knows from his own sad personal experience in Kansas. Examples of this kind could easily be multiplied.

Other lines of evidence give partial support to the prevalent idea, but introduce elements of doubt. Recent experience in testing hybrid types of sweet corn in Connecticut furnishes an example. These hybrids have been developed from inbred strains of varieties that originated many years ago in southern New England, or nearby regions, and have always been grown there. In this section these varieties produce remarkably fine yields of well-formed, attractive ears. The best of the crosses derived from them are even more productive and attractive in ear formation. When seed of these new hybrids is sent to Maryland, Ohio, or Michigan, the reports are seldom favorable. Occasionally some types do fairly well, but not enough better than local varieties to justify extensive use. Invariably the reports from Illinois, Missouri, and Kansas indicate almost complete failure every year. It is hopeless to try to grow sweet corn from New England in those sections. The leaves begin to roll early in the season even when the soil is well supplied with moisture.

On the other hand, when the new hybrids are tested in certain other places, they do well. From central New England, New York, and some parts of Pennsylvania the reports are often favorable. Some Connecticut hybrid sweet corns have been grown for canning for

[1]Contribution from the Department of Genetics, Connecticut Agricultural Experiment Station and Yale University, New Haven, Conn. Received for publication February 1, 1935.

[2]Geneticist and Geographer, respectively.

many years in central New York with satisfactory results. Where they are not too late in maturing they usually do well in Massachusetts, southern Vermont, New Hampshire, and Maine. Somewhat to our surprise, many enthusiastic reports have also been received from northern Nevada, southern Idaho, and eastern Washington. There yields on some of our hybrid sweet corn have surpassed the production here.

The idea that corn seed from a distance does not grow well in new regions is rendered still more doubtful by other experiments. In Connecticut nearly all varieties of sweet corn that have been developed farther west and south grow remarkably well. Varieties from as far away as Florida and California have given good yields. Some of the newer sorts surpass the best local types in yield. Moreover, it is a regular practice in New England to grow ensilage corn from seed produced in many far distant regions. Much seed for this purpose is brought in from Iowa and Nebraska, partly on account of the low cost. Nearly all of this produces well-filled ears, and these often ripen sufficiently for husking. Curiously enough, the maximum yields of dry matter are produced from varieties native to Virginia and the Carolinas. Varieties such as Cocke's Prolific, Pamunkey, Shenandoah, and Golden Beauty, which seldom grow more than 9 or 10 feet tall in their native environment, regularly grow from 12 to 14 feet in southern Connecticut. In the majority of years the grain on these plants reaches the hard dough stage and in some years the ears can be husked and shelled. Yields of 50 bushels and more of dry shelled grain are common. Even when ears are not formed the production of dry matter is significantly more than from the largest Pennsylvania and Maryland varieties and much more than from the best local sorts.

It was formerly thought, without good evidence, that the dry matter in these late-maturing varieties was not equal in feeding value to the dry matter from more mature corn with a larger proportion of grain. White and Johnson (1)[3] and others at the Storrs, Conn., Experiment Station have shown that this is a serious error. Jones, Slate, and Brown (2) have tested the yield of corn from different parts of the country for 7 years at Mount Carmel, in southern Connecticut, and at Storrs, in the north central part of the state. Thus, the tests were carried out in two different biological zones (Upper Austral and Transitional) and on two distinctly different types of soil.

The varieties thus tested are grouped in Table 1 according to their place of usual cultivation. The figures there given show bushels of dry shelled grain expressed as percentages of the yield of the standard variety grown for comparison each year. This form of comparison is necessary because all varieties were not grown every year. The varieties are placed in four groups, *viz.*, Connecticut; New York and Massachusetts; Pennsylvania, Delaware, Ohio, Wisconsin, and Illinois; and the highest yielding Connecticut varieties. For the most part the varieties from outside Connecticut either originated in the

[3]Figures in parenthesis refer to "Literature Cited," p. 270.

states named or had been grown there long enough to be considered well adapted to their locality. Many Connecticut varieties had been grown here for more than 50 years. Some were more recent introductions from other states. Such high yields in Connecticut from seed grown at a distance are especially significant because the average yield of all local varieties of corn per acre is larger in Connecticut than in any other state.

TABLE 1.—*Relative yield of grain from dent varieties of corn from different sources in percentage of the standard variety grown in comparison each year.*

No.	Source	Mount Carmel, Conn.		Storrs, Conn.	
		Number of varieties	Yield %	Number of varieties	Yield %
1.....	Conn.	51	105.5	49	102.0
2.....	New York and Massachusetts	8	110.5	7	100.0
3.....	Penn., Del., Ohio, Wis., Ill.................	5	122.7	6	120.0
4.....	Highest yielding Conn.	5	128.1	6	122.3

It will be seen from Table 1 that on an average the seed from states adjoining Connecticut yields about the same amount of grain as local varieties, both at Mount Carmel and at Storrs. Seed from more distant regions is significantly more productive than the average of all local varieties at both places. This is due in part, possibly, to the fact that these distant varieties are adapted to a longer growing season. Many local varieties may mature too early to make the best use of our seasons. Other factors may be involved. Collins (3) has shown that there is a definite stimulus to increased production following a change in environment. By selecting an equal number of the highest yielding local varieties out of the large number grown, an obviously unfair comparison, we can make a little better showing for Connecticut-bred corn. The differences are not significant, and it cannot be said that locally grown varieties will produce more grain in these two different sections of Connecticut than varieties brought in from a thousand miles away. All that can be claimed is that local varieties will mature a better quality of grain, especially in unfavorable and short growing seasons.

Relatively little corn is grown for grain in New England. The bulk of the production is for ensilage. For this purpose the total yield in pounds of dry matter should be the chief consideration. Other important factors are involved which need not be discussed here. Dry matter determinations for the entire plant were made for the larger varieties included in the above tabulation and these are averaged for local and distant sources of seed. Again the yields are expressed in percentage of the standard variety grown each year. The results are given in Table 2.

Varieties from Connecticut, Massachusetts, and New York are placed in one group and all other varieties in another group. The local varieties are mostly adapted strains of Leaming, Reid's Yellow

Dent, White Cap Yellow Dent, and others with similar growing seasons. The distant varieties are as follows: From Pennsylvania, Lancaster Sure Crop, West Branch Sweepstakes, Clarage, and similar varieties; from Ohio and Illinois, Leaming and Funk's 90 Day; and from Delaware and Virginia, Eureka, Mastodon, Golden Beauty, and similar sorts.

TABLE 2.—*Relative yield of dry matter from ensilage varieties of corn from different sources in percentage of the standard variety grown in comparison each year.*

Source	Mount Carmel, Conn.		Storrs, Conn.	
	Number of varieties	Yield %	Number of varieties	Yield %
Conn., Mass., N. Y.	39	67.1	50	80.1
All others	7	85.4	10	84.8

In southern Connecticut the production of dry matter by the distant varieties is distinctly more than from the local varieties, while in the north central part of the state the production by the two types is about the same. From this trial and from feeding tests conducted at Storrs, the value of the larger and later southern varieties was realized. Consequently, a large number of varieties from the south and west were collected for a preliminary trial. From these a smaller number of varieties that seemed best suited to Connecticut were selected and grown for 4 years in comparison with the highest yielding local variety at Mount Carmel. Each variety was replicated five times and compared with the adjoining check rows on each side. The production stated as tons of water-free dry matter per acre is given in Table 3. (See Fig. 1.)

TABLE 3.—*Actual yield of dry matter per acre from ensilage varieties of corn from different sources grown at Mount Carmel, Conn.*

No.	Source	Number of varieties	Yield of dry matter, tons
1	Conn.	1	3.5
2	Penn.	3	3.4
3	Ohio, Ill.	4	3.6
4	Ga., La., Texas	3	3.9
5	Va., Carolinas	7	4.2

The Connecticut variety used for comparison was Burr-Leaming, a hybrid type developed partly from Illinois and partly from local Connecticut varieties, all grown here for about 20 years and well adapted to local conditions. It had about the same time of maturity as the Pennsylvania varieties used in this trial, which were again Lancaster Sure Crop, West Branch Sweepstakes, and Clarage. It regularly produced more grain than these varieties, but did not appreciably excel them in total dry matter, as shown in Table 3. The Ohio and Illinois varieties were various strains of Leaming and Funk's

FIG. 1.—Ensilage trials at Mount Carmel, Conn., in 1934. Varieties from Virginia and the Carolinas in the foreground. Photograph taken August 29.

90 Day. These yielded about the same as the Connecticut and Pennsylvania varieties. The Georgia, Louisiana, and Texas varieties were Yellow Creole, Hasting's Prolific, and Tuxpan. These were the latest in maturity and yielded somewhat more than the first three groups, but not as much as the fifth. Virginia and the Carolinas were represented by the varieties known as Cocke's Prolific, Pamunkey, Eureka, Golden Beauty, Virginia Pride, Blue Mountain, and Shenandoah. These produced 4.2 tons of dry matter per acre, about 8% more than the next highest group and 20% more than the standard Connecticut variety.

The evidence presented thus far in this article indicates that when seed corn is carried from one location to another the yield sometimes increases and sometimes decreases. Seed from Connecticut when planted elsewhere appears to be less productive than in its own locality except in certain northern areas. On the other hand, when seed is brought from practically any other part of the country to Connecticut the yield of both grain and vegetative matter appears to increase notably. The mere fact of a change of environment, regardless of the type of change, cannot explain these contradictory findings. The fact that Connecticut has the highest yield of corn among the states of the Union must also be considered. Connecticut produced 46 bushels per acre as a 20-year (1910–1929) average in contrast to 45 bushels in Massachusetts, which stands next, 42 in Pennsylvania, and 38 in Iowa, which is popularly supposed to be the best corn state. Corn seldom leaves the farm in New England and for that reason may not be so accurately estimated as in some of the other states. This is equally true for many other states and a large part of the crop in all states. Moreover, the average yields gradate so evenly from place to place that they seem to be reasonably reliable.

The high yield of corn in southern New England has usually been attributed to the small size of the fields. This is supposed to have led to careful cultivation together with more adequate fertilization. The average corn field in Connecticut not only has poorer soil than the average field in a state like Iowa, but it is not cultivated any better, if as well, and as a rule does not receive much more fertilization than many middle Atlantic states where the rainfall is equally heavy. In the middle western states the soil is so well supplied with plant food that there is little response to added elements even in years of abundant rainfall. In Connecticut, corn for grain is not always raised on the best soil. Farmers give their most productive land and most of their care and fertilizer to fields devoted to more profitable crops like sweet corn, potatoes, and other vegetables. Therefore, neither soil, cultivation, nor fertilization seem to afford an adequate explanation of the high yield per acre.

That the climate of New England could be especially favorable to the development of corn or any other crop has seldom been admitted by western enthusiasts. Nevertheless, Huntington, Williams, and Valkenburg (4) find a remarkably close connection between climate and the yield of corn as well as of other crops. They have analyzed the climatic factors of both rainfall and temperature by seasons in respect to yield of corn per acre. They based their study on the average yield

for 16 years in all the states outside of New England where corn is produced in reasonable quantities without irrigation. In this way they found that the highest yields were obtained when all four of the seasons, including even the winter, were identical with the average for Connecticut. They found also that in all parts of the world the yield of corn per acre varies in harmony with the climate.

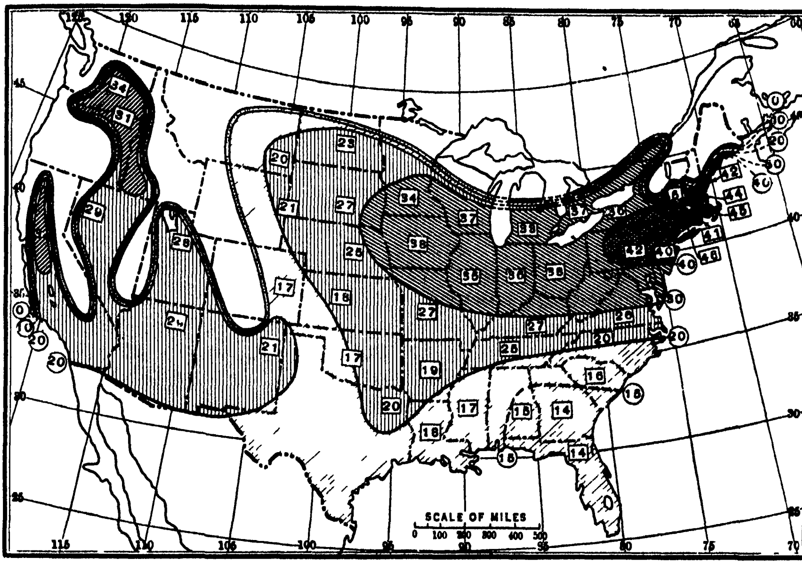

FIG. 2.—Average yield of corn per acre in the United States, 1910–1929, shown by isopleths. (From Huntington, Williams, and Valkenburg's *Economic and Social Geography*. By courtesy of John Wiley & Sons.)

In other words, for corn, as for every other plant and for animals, there is a definite climatic optimum. This optimum includes not only the summer but the rest of the year. If only three months—May, June, and July—are favorable and all the rest of the year highly unfavorable the yield may be only 10 bushels per acre. As the length of the favorable period increases, the yield also increases. The apparent reason why Iowa in spite of its excellent soil fails to equal the southern New England and Middle Atlantic states and only rises to the same level as Ohio and Maryland is that cold, dry winters, an occasional dry spring or fall, and excessive heat during dry spells in summer do more damage than in the states farther east.

The general distribution of the yield of corn per acre in the United States is shown in Fig. 2. Starting in Connecticut, where the yield is highest, the averages fall rapidly toward the north and more slowly toward the south along the Atlantic coast, reaching a minimum of 14 bushels in Georgia and Florida. From southern New England directly westward the average yield falls steadily. On the map there appears to be an exception because Indiana and Illinois rank lower than Iowa, but if only the northern parts of these states and of Ohio were included the exception would probably disappear. It is notice-

able, however, that from southern New England westward there is a belt of high yield which has its western limit in southeastern South Dakota and northeastern Nebraska. In spite of the obvious effect of aridity in Nebraska and Wyoming, this belt extends still farther westward. Among the Rocky Mountains, to be sure, it is interrupted, for practically no corn grows there because of the high altitudes and low temperatures. In Washington, however, the belt of high yield per acre reappears. Northward from this belt the yield of corn everywhere decreases very rapidly until low temperature prevents the crop from being grown; southward the yield diminishes slowly.

From these facts and from the distribution of corn elsewhere, Huntington, Williams, and Valkenburg deduce the rule not only that corn has a distinct climatic optimum, but that *the yield per acre is highest near the coldward limit of possible cultivation.* This is true not only for corn, but for many other crops in this country and in other parts of the world.

With this brief outline of the important climatic conditions governing crop production before us, let us now consider another general rule of crop adaptation that seems to develop from this study of the behavior of corn from widely different regions. *Corn may be moved from a less favorable to a more favorable climatic region without loss of productive capacity, and usually with distinct gain*, provided the length of the growing season permits satisfactory maturity. If this be true, a new variety originating in Indiana, for example, would presumably do still better in Pennsylvania; one originating in Nebraska would show similar improvement when moved to Iowa. Adaptation to different soil types and levels of fertility must, indeed, be taken into consideration, especially where deficient elements are not supplied by proper fertilization. In our tests in Connecticut, however, marked differences in types of soil have not made much difference in relative performance.

The converse of the law italicised above is also true. It may be stated in another form as follows: *Most of the loss in productivity when seed corn is taken from one region to another is due to less favorable conditions of climate.* In many, perhaps most, cases the varieties originating in the more favorable climates seem to lack the power to resist the heat and drought of the less favorable regions. The good varieties taken from the less favored to the more favored climatic areas seem to have a virility which causes them, for a while at least, to excel the varieties originating in the most favored areas.

From all this it seems clear that these climatic relationships must have a tendency to cause good varieties to be moved toward the localities that are climatically most favorable. Suppose a new variety is produced in Georgia and gives an average yield of 16 bushels per acre instead of 14, which is now the rule for all varieties. If it is moved to North Carolina it may be expected to increase its yield in the ratio of even more than 14 to 20, which is the average relation between the yields per acre in these two states. This might mean a yield of 23 or 24 bushels per acre. So good a variety would naturally be carried farther north with still better results. Its northward movement would be checked only when the growing season became too short.

On the other hand, a variety originating in the northeastern United States within the heavily shaded optimum area of our map is likely to suffer the opposite fate. No matter which way it is moved it is likely to be less productive than in its original home. If it has become well adapted to the relatively cool summer of a state like Connecticut, it suffers from the heat when it is moved westward or southward.

Much of the prejudice against seed corn from a distance is no doubt due to the fact that seed is more generally moved, in the central states at least, from the better to the poorer corn growing regions. When a farmer is seeking new seed he goes to the neighbor that produces better corn than he does. When seed must be brought into a region on account of a crop failure only the more favored sections have seed to send. Most commercial seedsmen produce their crops in those locations where the most attractive crop can be grown at the lowest cost.

In some cases, when improved varieties are moved away from the optimum area, they produce more abundantly than the local varieties in the new area, even if not so abundantly as in their place of origin. More exact information is needed on this point. It is hoped that this article will call attention to the desirability of widespread experiments in which seed corn shall be exchanged between widely separated regions in such a way as to test all sorts of climatic relationships.

As a step in this direction, the facts set forth in this article seem to shed new light on the perplexing problems of why the yield of corn varies so greatly from region to region and of what conditions determine how seed may most profitably be transferred from one region to another. Both problems are involved in the question of the precise conditions which enable Connecticut and the surrounding regions to raise so much more corn per acre than any other sections. The most fundamental condition seems to be that here the climate is almost ideal for corn *at all seasons*. The summers are sufficiently warm and rainy, but are not often subject to either extreme heat or extreme drought. The growing season is fairly long, and both the spring and fall rarely experience droughts or unseasonable frosts which produce any such extreme effects as are common farther in the interior in the same latitude. And finally, the winters are only moderately cold and have sufficient rain and snow. Hence the soil is generally saturated with moisture in the spring. This reduces the danger that the thin but highly valuable upper layer of soil will be blown away by the wind or that the soil as a whole will be so dry as to hamper the growth of the seed. Any departure from this optimum, even in winter, appears to lessen the yield of corn per acre. Thus, in transporting seed from one section to another we need to take account not only of the summer but of the whole year. In this way we can form a fairly good estimate of how well the transported seed will thrive and what yield it will give. In general, unless it is moved too far, any given variety might be expected to vary from state to state in approximately the same way that the average yield of all varieties varies over long periods as shown on the map. There is some indication, however, that the change to another climate produces an even greater effect than would be expected on this basis.

A second broad generalization also needs emphasis. The concentration of high yields of corn in a northern belt from Connecticut to Iowa is reenforced by other causes in addition to the direct effect of climate. These other causes, to be sure, are also climatic, but only indirectly. The first of them is soil. In a broad way the best quality of soil is produced where the climate is medium in two respects. The medium in one respect is found about half way from the equator to the poles in about the latitude of the greatest productivity of corn. The other is found in the grassy regions midway between the eastern forests and the western or central arid regions of a continent. Iowa, with its wonderful soil, is like the Ukraine of Russia in being located where both of the favorable types are combined.

Another factor, indirectly climatic, which determines the northward location of the belt of maximum yield per acre is the prevalence of pests. Many of these, such as the corn ear worm, weevil, and bacterial wilt, thrive in the South but are hampered by cold winters in the north. A human factor is probably still more important. For centuries the mere fact, that, when seed corn is transported northward, its productivity increases, has presumably resulted in a strong tendency to carry good types of seed northward. The opposite tendency has been discouraged because northern seed when carried south in our hemisphere yields less than in its original habitat. Many local factors of both soil and climate undoubtedly modify the general rules as to the climatic optimum and the northward concentration of high yields. Nevertheless, the experience of Connecticut with both field and sweet corn tends to confirm these wide generalizations.

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BORON DEFICIENCY IN TOBACCO UNDER FIELD CONDITIONS[1]

J. E. McMurtrey, Jr.[2]

THE present definite trend in the fertilizer industry toward the use of relatively pure chemicals to replace the much more complex materials previously employed has accentuated the need of an adequate knowledge of the effects on plant growth of all essential elements. Obviously, use of the highly concentrated materials as the chief or sole sources of nitrogen, phosphorous, and potassium may result in mixtures containing little, if any, of various other elements known to be essential for the higher plants. That boron is an essential element for higher plants has been demonstrated by several investigators in recent years (1, 2, 3, 4, 5, 6, 7).[3] In previous papers (4, 5), the writer has described the distinctive effects of boron deficiency on the growth of tobacco. It was pointed out also (4) that it is possible to obtain symptoms of boron deficiency in pot cultures using field soil.

As far as is known the occurrence of boron deficiency under field conditions has been described only from Sumatra (3) where it is reported to produce a characteristic disease of tobacco known as top-sickness (Topziekte).

METHODS OF EXPERIMENTATION

A series of plats to study the effects of varying rates of calcium application on yield and quality of tobacco was started in 1928 and tobacco has been grown on them each year since then. The plats were located at Upper Marlboro, Md., on a phase of the Collington series which is quite sandy and could probably be designated as loamy sand with some gravel admixture. The fertilizer mixture was prepared from mono-ammonium phosphate, calcium nitrate, ammonium nitrate, potassium sulfate, and magnesium sulfate. None of these salts were ot the C. P. grade. The materials were applied each year in quantities to furnish 80 pounds of nitrogen (N), 80 pounds of phosphoric acid (P_2O_5), 100 pounds of potash (K_2O), and varying quantities of calcium per acre. Since the quantities of calcium furnished are not to be discussed in this paper, it is sufficient to state that 115 pounds ot CaO were supplied as calcium nitrate on the plats under consideration. Magnesia (MgO) was applied at the rate of 20 pounds per acre and sulfur at the rate of 125 pounds of SO_3 per acre.

DISCUSSION OF RESULTS

In 1933 the tobacco developed the characteristic die-back of the terminal bud previously described (4, 5) as distinctive for boron deficiency when the plants were grown in solution cultures and in pot

[1]Contribution from Division of Tobacco and Plant Nutrition, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating with Maryland Agricultural Experiment Station. Received for publication January 17, 1935.

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[3]Figures in parenthesis refer to "Literature Cited," p. 273.

cultures with soil and sand Since this condition was more or less common on all treatments, there was no absolute check as to whether it was due to boron shortage. However, on a plat in another series fertilized with a mixture in which the potash was derived from a commercial potassium chloride containing boron, this die-back of the terminal bud was not observed.

In order to determine if the diagnosis of this trouble was correct, boron was applied in 1934 at the rate of 5 pounds per acre of chemically pure boric acid (H_3BO_3) to two plats and omitted from duplicate treatments in this series

FIG. 1.—Tobacco plants from field transplanted to buckets to facilitate photographing A, early manifestations of boron deficiency characterized by light green color at the base and drawn appearance of bud leaves. B, extreme boron deficiency showing die-back of the terminal bud, rolling of upper leaves, and associated phenomena.

On plats which received no boric acid the characteristic effects of boron deficiency again were apparent, being particularly marked on one of them. The effects did not develop where boron was supplied. It is important to call attention to the fact that boron may become toxic to plant growth unless used in very small quantities. No toxicity was observed with the quantity used in this instance.

The following are distinctive effects of boron deficiency on tobacco. First, the young leaves composing the bud exhibit a light green color, the bases of the individual leaves manifesting a lighter green than the tips. When this condition appears, the bud leaves have ceased to grow and exhibit a somewhat drawn appearance as seen in Fig 1, A. This condition is followed by a breaking down of the tissue at the base of the young leaves making up the bud. Death of the terminal bud is the final manifestation, as shown in Fig 1, B. The automatic topping of the plant results in a thickening and an increase in area of the leaves. Finally, the leaves become glabrous and brittle, and when the midrib is broken, the vascular tissue shows discoloration. The upper leaves tend to roll in a half circle downward from the tip toward the base (Fig. 1, B). When the boron deficiency is not too extreme so that lateral buds (suckers) develop in the axils of the leaves or at the base of the stalk, these generally break down, as described above.

When the earlier stages do not progress too far and the young leaves later make fair growth, they may be distorted by twisting to one side because of growth around the injured tissue. The stalk toward the top of the plant in the same fashion may show a one-sided or twisted growth.

SUMMARY

The recent trend toward the use of relatively pure chemicals in the fertilizer industry emphasizes the importance of all elements essential to plant growth. After using such chemicals in preparing fertilizer mixtures for tobacco on a sandy soil for a period of 5 years pronounced effects of boron deficiency became apparent.

The first indication of boron deficiency is a light green color of the bud leaves especially at the base of the individual leaves, which is followed rapidly by more or less breakdown of the tissue. When the breakdown does not involve all the tissue and later growth takes place, such leaves are distorted by growth around the injured areas. In the same manner the stalk toward the top of the plant may manifest a one-sided or twisted growth. The final manifestation is a die-back of the terminal bud. Lateral buds (suckers) may develop in the axils of the leaves or at the base of the stalk, but they usually break down as described above.

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THE RELATION OF VARYING RAINFALL TO SOIL HETEROGENEITY AS MEASURED BY CROP PRODUCTION[1]

W. H. METZGER[2]

THIRTY-SIX field plats, each 1/20 acre in size, were established at the Kansas Agricultural Experiment Station in 1925 for the purpose of expanding the soil fertility investigations. Careful examination of profile samples showed no marked variations in the physical constitution of the soil of the area covered by these plats. It was considered desirable, however, to crop the plats uniformly for a few years before treatments were inaugurated in order to determine natural variability of the soil. Shortage of funds delayed the beginning of the fertilizer treatments longer than had been planned with the result that the plats have now been uniformly cropped for 10 years. Yields have been obtained in only 9 years, however, because an exceedingly heavy chinch bug migration in 1933 resulted in the loss of a crop of Atlas sorgo.

During this period of years rainfall varied greatly and field observations indicated that the amount of rainfall was an important factor influencing the variability of the crop-producing power of the soil. The yields confirmed these observations. A study has, therefore, been made of this relationship.

MATERIALS AND METHODS

The crops grown in the 9 years were as follows: 1925, corn; 1926, oats; 1927, wheat; 1928, wheat; 1929, alfalfa; 1930, alfalfa; 1931, alfalfa; 1932, Atlas sorgo; 1934, Atlas sorgo. The 1933 crop was lost as explained previously. The mean yields and the deviations for each crop were determined. The deviation of the yield of each plat from the mean was expressed as percentage of the mean and the values so obtained were averaged. This method of expressing variability was used by Garber and Hoover (2)[3] and by Garber, McIlvain and Hoover (3) and affords a measure of such variability based directly on actual yields.

RAINFALL AND YIELD VARIABILITY

The yields of the various crops during the 9 years failed in a large proportion of the cases to show the persistent soil differences which were reported by Harris and Scofield (4) and by Garber and Hoover (2). Certain plats rather consistently ranked high in yield and others fairly regularly ranked low, but the great majority of the plats were erratic in their yield performances. It was believed this might be the result of moisture supply being the dominant limiting factor in crop production in certain years rather than any nutrient deficiency. The

[1]Contribution No. 242 from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication January 14, 1935.

[2]Assistant Professor of Soils. The field work yielding the results on which this study was based was directly supervised by Dr. F. L. Duley during the years 1925–1931.

[3]Figures in parenthesis refer to "Literature Cited," p. 278.

uneven appearance of crop growth in the dry years as contrasted with a more uniform appearance in normal seasons strengthened this belief.

In studying the relationship of rainfall to these yield variations the period of September 1 to September 1 was selected as that best representing an effective rainfall year for the six grain-producing crops, corn, oats, two crops of wheat, and two crops of Atlas sorgo. The three alfalfa crops were considered separately because no crop year basis could be selected which included to a similar extent the effective rainfall for the alfalfa crops and the grain-producing crops. The total annual yield of alfalfa at Manhattan is usually largely determined by the first and last cuttings and therefore rainfall after September 1 often greatly influences the yield for the current season.

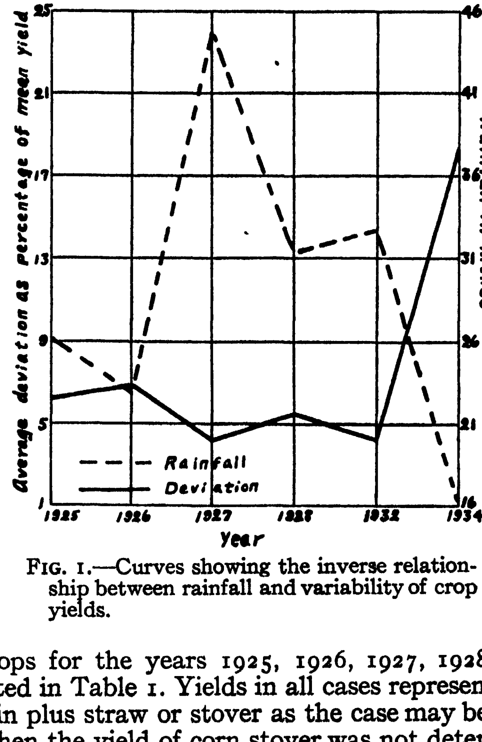

FIG. 1.—Curves showing the inverse relationship between rainfall and variability of crop yields.

The rainfall and the variability of the yields of the grain-producing crops for the years 1925, 1926, 1927, 1928, 1932, and 1934 are presented in Table 1. Yields in all cases represent total produce, that is, grain plus straw or stover as the case may be, except for the year 1925 when the yield of corn stover was not determined.

TABLE 1.—*Rainfall and variability of yields of grain-producing crops from 36 uniformly cropped plats.*

Year	Rainfall, Sept. 1 to Sept. 1, inches	Yield deviations expressed as percentage of the mean
1925	26.17	6.46
1926	22.69	7.28
1927	45.02	3.97
1928	31.32	5.47
1932	32.64	4.04
1934	16.15	19.11

The data of Table 1 are shown graphically in Fig. 1. It is strikingly evident that a high negative correlation exists between the rainfall and the extent of variability of the crop yields. The correlation coefficient was calculated and found to be: $r = -.772 \pm .111$.

This coefficient was calculated on the basis of an assumption that the relationship was linear. A somewhat higher value might have been obtained by the use of the formula for the coefficient for a non-linear relationship, but the value here given indicates a highly significant negative correlation.

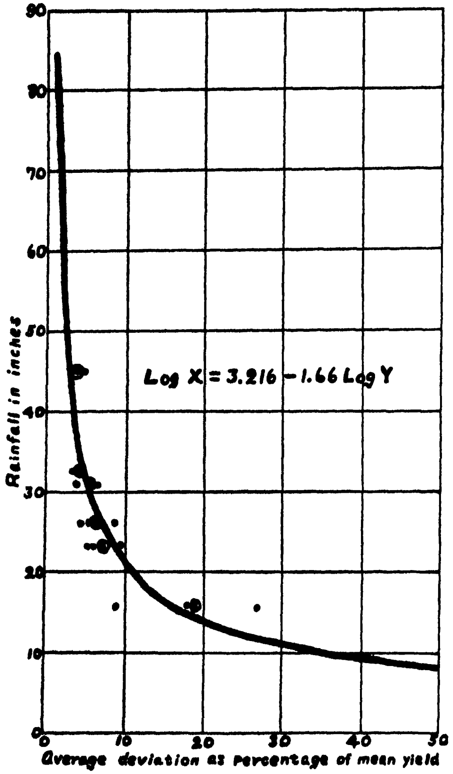

FIG. 2.—Regression of yield deviations on rainfall for six grain-producing crops, corn, oats, wheat, wheat, Atlas sorgo, and Atlas sorgo.

A dot chart is presented in Fig. 2 in which the rainfall is plotted against the percentage deviation, the values from Table 1 being shown as dots inclosed by circles. Since the 36 plats are divided into three series of 12 plats each, the values for each series are also shown, the dots in this case not being circumscribed. The use of these dots shows more completely the spread of the percentage deviation values for the various plats. The regression is non-linear and may be represented by the equation:

$$\log x = 3.216 - 1.66 \log y.$$

The data and curves indicate clearly that low rainfall, under the conditions existing at Manhattan, Kans., brought about high variability in the crop-producing power of the soil of these plats. When rainfall was adequate the soil produced much more uniform crops.

Such a relationship is perhaps common to areas where rainfall is frequently a limiting factor in crop production. Support for this affirmation is supplied in data assembled from a publication by Finnell (1) of the Oklahoma Experiment Station. These data are presented in Table 2.

The correlation coefficient for Finnell's data was calculated and found to be $r = -.9149 \pm .0449$. The regression is non-linear. The same principle is illustrated in the data from the two sources, Oklahoma and Kansas, namely, that a low moisture supply increases soil heterogeneity as measured by crop yields and high moisture supply produces greater uniformity.

Using calendar year rainfall figures, since the calendar year fulfills the requirement of a good crop year for alfalfa, the percentage devi-

ation values for the alfalfa crops of 1929, 1930, and 1931 show a similar relationship to rainfall. These values are listed in Table 3.

TABLE 2.—*Available moisture in the surface foot of soil and the coefficient of variability of crop yields, 9 years (Finnell).*

No. of plats	Depth of subsoil, feet	Culture	Average percentage available moisture	Coefficient of variability of yield
1.......	6	Continuous wheat	6.83	107.6
1.......	4	Continuous wheat	5.19	112.2
2.......	6	Wheat-fallow	8.96	75.2
2.......	4	Wheat-fallow	7.24	83.8
3.......	6	Wheat-fallow-fallow	8.29	77.4
3.......	5	Wheat-fallow-fallow	8.05	81.0

TABLE 3.—*Rainfall and percentage deviation of alfalfa yields.*

Year	Rainfall Jan. 1 to Jan. 1, inches	Yield deviations expressed as percentage of mean yield
1929..................	33.65	10.37
1930..................	34.18	8.06
1931..................	38.75	4.88

The correlation coefficient for the alfalfa crops was found to be $r = -.936 \pm .048$. Despite the extremely high correlation indicated by this value, no great validity is attached to these data. Only three measurements are involved and the spread in rainfall values is not great. Considered along with the preceding data, however, the values for alfalfa lend weight to the previously presented evidence regarding the influence of rainfall on soil heterogeneity as reflected in crop yields.

The existence of this type of relationship does not increase confidence in the results of field investigations as they are frequently conducted, especially in regions where rainfall is often deficient. The results emphasize the need for consideration of the use of smaller plats and more replications in field experiments than are frequently employed.

Summerby (5) has recently presented data showing the need for replication even where preliminary uniform cropping has been practiced for the purpose of measuring variability in the soil.

SUMMARY

The variability of crop yields from uniformly cropped field plats receiving no fertilizer, manure, or lime treatments was studied in relation to rainfall. High negative correlations were found between rainfall for the "crop year" and soil heterogeneity as reflected in crop yields. Calculations from data assembled from a publication of the Oklahoma Experiment Station show a similar relationship between moisture supply in the soil and yield variability.

The existence of such a relationship emphasizes the need for smaller plats and more replications in many field experiments. It also decisively limits the value of a uniform cropping period as a means of establishing definite variability in the crop-producing power of a group of experimental plats.

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UNIFORMITY TRIALS WITH RICE[1]

CHIEN-LIANG PAN[2]

MODERN systems of field plat technic, together with the new statistical method of interpreting data known as the "Analysis of Variance," have been introduced. The use of systematically replicated plats with frequent check plats for correction of yields is not as prevalent today as it was a few years ago. In their place randomized blocks have been substituted. Unfortunately, however, few comparisons of the mathematical reliability of the two methods have been made with actual data. In the present paper the two methods are compared and a study is made also of the comparative efficiency of plats of different sizes.

LITERATURE REVIEW

In 1933 Love (7)[3] introduced a method into China for the breeding of rice varieties similar to the method used at Cornell University (5, 6). Student's method, originally used for interpreting the data of advanced tests, was abandoned and Bessel's formula for calculating the probable error was used for all comparisons. By this method a probable error was calculated from the check plats and expressed in percentage of the mean. This average probable error in percentage of the mean was multiplied by the square root of 2, to obtain the average probable error of a difference in percentage. The average yield of each strain was computed and its gain or loss as compared with the yield of its theoretical check was calculated. The probable error of this gain or loss was computed by multiplying the average yield of each variety or strain by the percentage probable error of a difference. For significance, the gain of a strain over its theoretical check should be at least 3 times the probable error of a difference.

The use of randomized blocks as devised by Fisher (1) appears to be a promising method of making preliminary comparisons of strains obtained from head selections. By use of Fisher's (2) analysis of variance it is possible to divide the total variance into its components, thus allowing for the removal of the variance due to known causes, such as blocks and varieties.

The relative desirability of different sizes and shapes of plats was studied by Immer (3), who worked with sugar beets; by Kalamkar (4), who worked with potatoes; and by Lord (8), who worked with rice. In general, these studies indicated that the experimental variability was decreased when the size of plat was increased and that long narrow rows were preferable to short wide ones.

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[1]Contribution from the Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. These data were taken when the writer was Junior Agronomist at the Provincial Agricultural Experiment Station of Chekiang, China. The paper was submitted to the Graduate School of the University of Minnesota as partial fulfillment of the requirements for the degree of master of science, June 1934. Received for publication January 21, 1935.

[2]Graduate Student. The writer wishes to express his appreciation to Dr. H. K. Hayes, Chief of the Division of Agronomy and Plant Genetics under whose personal direction the statistical studies were made.

[3]Numbers in parentheses refer to "Literature Cited," p. 285.

MATERIALS AND METHODS USED

Three varieties of rice were used in this study. Two were medium-maturing varieties with a growing period of approximately 130 days and the other a late-maturing variety with a growing period of more than 150 days. One of the two medium-maturing varieties and the late-maturing variety were grown in the rice breeding nursery field at the central station of the Provincial Agricultural Experimental Station of Chekiang, China, located at Hangchow. The other medium-maturing variety was grown at the substation located at Wufu about 70 miles from the central station.[4]

The method ot direct planting in the row was used instead of transplanting. The medium-maturing varieties were planted in 1931 early in May, and the late-maturing variety was planted early in June. The varieties were harvested in the middle of September and early in November, respectively. Rectangular fields consisting ot three series of 100 rows each were used for each variety. Each row was 14.2 feet long with a 1.5 foot space between the rows. Each series was separated by a 2-foot alley and the rows ran from north to south. The medium-maturing varieties were sown at the rate of 10 grams per row, while for the late variety only 8 grams per row were used. The calculated yield in bushels per acre for single row plats was obtained by multiplying the yield in grams by 0.1.

EXPERIMENTAL RESULTS

SIZE AND SHAPE OF PLATS

The study was made on the basis of 25 varieties to be tested. If these were to be tested in single-row plats much less land would be needed than for three-row plats. As a rule larger areas of land are more heterogeneous than smaller areas and, therefore, the calculations were made on the basis of the actual area that would be used in a test of 25 varieties. There were, however, 300 rows in all in each of the three studies; consequently, the study of variance in single-row plats comprised 12 groups of 25 rows each. The data presented represent the average variance for single-row plats with the block differences removed. Similarly, for two-row plats the computations were on the basis of the actual area in each group of 25 hypothetical varieties.

Two methods were used for determining the most desirable size and shape of plats in order to find whether it is more desirable to increase the width or the length of the row. Four different widths of plats were studied, namely, single-row, two-row, three-row, and four-row plats. The single-row plat comprised an area of 21.3 square feet, while the areas covered by two-, three-, or four-row plats were 2, 3, or 4 times as great. Three different lengths of row were studied, namely, single-row, two-row, and three-row length. The area of these three different lengths of rows was the same as the area of plats one, two, or three rows in width. The yield of plats of two-row length was obtained by adding the yields of the corresponding rows in the first and second series for the study designated as A, and by adding the yields of rows in the second and third series for the study designated as B.

The calculated results for the different sizes and shapes of plats are given in Table 1. The data in Table 1 give the efficiency index of the

[4]The writer is indebted to H. N. Shen who furnished the data used.

different sizes and shapes of plats. This index was calculated by dividing the variance of a single-row plat by the product of the variance of a multiple-rowed plat times the number of rows included in this plat and expressing the result in percentage.

TABLE 1.—*The experimental variability for different sizes and shapes of plats of the two rice varieties grown at the Hangchow Central Station and of the variety grown at the Wufu Substation.*

Size and shape of plats	Medium-maturing variety grown at the Hangchow Central Station		Late-maturing variety grown at the Hangchow Central Station		Medium-maturing variety grown at the Wufu Substation	
	Variance	Efficiency	Variance	Efficiency	Variance	Efficiency
1-row	35.049	100.00	27.697	100.00	49.036	100.00
2-row	16.066	109.08	15.720	88.09	45.955	53.35
3-row	14.084	82.95	10.392	88.84	46.047	35.50
4-row	12.286	71.32	11.547	59.96	39.480	31.05
2-row lengths, A	29.836	58.74	17.655	78.44	28.228	86.86
2-row lengths, B	24.396	71.83	18.976	72.98	36.389	67.38
3-row lengths	21.500	54.34	14.874	62.07	23.358	69.98

The data in Table 1 show that the single-row plat was the most efficient with the exception of the two-row plat of the Hangchow medium-maturing variety in which case the efficiency was 9% greater than the single-row plat. The data from Hangchow show that the increase in width of plat was more efficient than increase in length of plat, while in the experiment conducted at Wufu increasing the length of row was more efficient than increasing the width of row.

REPLICATION, RANDOMIZED ARRANGEMENT

Five replicated plats were used with 20 hypothetical varieties for each series of the experiment. Randomization was made by Tippett's method, and the analysis of variance was used for interpreting the data. The errors due to varieties and blocks were removed from the total sums of squares and the mean square for remainder was used as the experimental error. The standard deviation for a single determination expressed in bushels is the square root of the mean square for error. This may be converted into a generalized standard error in percentage for a mean of five replicated plats by the formula $\frac{\text{S. D.} \times 100}{m\sqrt{5}}$, where m refers to average yield and S. D. refers to standard deviation of a single determination in bushels. In order to study the efficiency of the randomized block method, comparisons of yield between the hypothetical varieties were made. There were 190 possible comparisons between these 20 varieties. The standard error in bushels of each hypothetical variety was obtained by multiplying the average standard error in percentage for five replicated plats by the mean yields of five rows of each hypothetical variety. The formula $\sqrt{(\text{S. E.})_1^2 + (\text{S. E.})_2^2}$ was used for calculating the standard error of the

difference between two varieties. After the differences in yields and standard errors between varieties were obtained, the next step was to find how many of these differences fell within 0.5, 1.0, 1.5, etc., times the standard error. The observed data are given in Table 2.

TABLE 2.—*Number of differences in yield between all possible comparisons within the hypothetical varieties that fell within 0.5, 1.0, 1.5, etc., times the standard error of a difference.*

Class ranges	Mathematical expectation	Hangchow medium-maturing variety	Hangchow late-maturing variety	Wufu medium-maturing variety
0.00–0.50 x S. E.	218.25	241	222	235
0.51–1.00 x S. E.	170.89	164	173	197
1.01–1.50 x S. E.	104.71	84	104	79
1.51–2.00 x S. E.	50.22	49	50	44
2.01–2.50 x S. E.	18.87	24	11	10
2.51–3.00 x S. E.	5.53	6	9	5
3.01–3.50 x S. E.	1.25	2	1	0

In Table 2, the class ranges set up are inclusive, that is the class 0.00–0.50 times standard error includes all deviations less than 0.5 times standard error or equal to it, while the class 0.51–1.00 times standard error includes deviations of more than 0.5 times standard error but including those equal to 1 times the standard error.

According to the law of probability, individuals differing from the mean by a magnitude of not more than 0.5 times the standard error of a difference comprise 38.29% of the total population. This percentage was multiplied by the total number of comparisons, giving the expected number of differences falling within the class 0.00–0.50 x S. E. The mathematical expectation of the other classes was calculated in a similar manner. A X^2 test for determining the agreement between observed results and mathematical expectation was calculated separately for each of the three experiments. In calculating the X^2 value, the classes with less than five individuals were combined. For example, the classes 2.51–3.00 x S. E. and 3.01–3.50 x S. E. of the medium-maturing variety grown at Hangchow were combined because there were but 1.25 calculated individuals in the latter class. The calculated values of X^2 and P are given in Table 3.

TABLE 3.—*The calculated values of X^2 and P of the three experiments for determining the agreement between the observed number of differences and mathematical expectation.*

Experiments	D/F	X^2	P
Hangchow medium-maturing variety	5	8.3890	.1435
Hangchow late-maturing variety	5	4.9078	.4350
Wufu medium-maturing variety	5	16.9946	——

The P values of the two experiments carried out at Hangchow exceeded 0.05 so the observed distribution of differences was considered to agree with mathematical expectation. The X^2 value of the Wufu

medium-maturing variety was 16.9946 which was greater than the value for P of 0.01. That is to say, such a deviation of the observed differences from the mathematical expectation would occur less than 1 time in 100 due to chance. It may be of interest to point out that in this experiment the discrepancy between observed and mathematical expectation was chiefly due to a larger number of comparisons in the classes 0.00 to 1.00 S. E. and a correspondingly smaller number in the higher classes.

REPLICATION, SYSTEMATIC ARRANGEMENT

Five replicated plats arranged systematically were used for each hypothetical variety with every fifth row as a check. Two methods were used for calculating the theoretical check. One was to consider the average of the two nearest checks as the theoretical yield for the rows in between the checks. The second was to grade the yields between checks as used by Love (5, 6, 7). The next step was to calculate the gain or loss in yield of each variety over its theoretical check. This was computed by direct subtraction of the yield of a variety from its theoretical check. The standard errors were calculated for each set of five replicated check plats by the formula $\sqrt{\frac{S(D^2)}{n(n-1)}}$, where D is the difference between the mean of each set of five plats and the yield of the individual plats and n is the number of replications. After the standard error of each set of the check plats was calculated, the generalized standard error in percentage was obtained by averaging the standard error of all sets of the check plats and then dividing the average standard error by the mean yield of the check plats and multiplying by 100. This generalized standard error in percentage, multiplied by the mean yield of five replicated plats of each hypothetical variety, gives the standard error in bushels of the variety. This standard error is then multiplied by the square root of 2, giving the standard error of a difference between the yield of the variety and its theoretical check. The number of differences in yield between the hypothetical varieties and their theoretical checks that fall within 0.5, 1.0, 1.5, etc., times standard error of a difference for the three experiments, together with the X^2 values for testing the agreement between observed and mathematical expectation, is given in Table 4.

The number of comparisons in each experiment was 16 which was too small for testing the agreement between observed number of differences and mathematical expectation The results from the separate experiments were combined and X^2 test was made. When the theoretical check was calculated by averaging the two nearby checks a calculated X^2 value of 23.6578 was obtained and when the theoretical check was calculated by grading the soil between each two pairs of checks the calculated value of X^2 was 19.8688. Both of these values give a P value smaller than 0.01, showing clearly that the observed differences did not agree with mathematical expectation. The lack of agreement appears to be the result of too many differences in the class 0.00–0.50 x S. E. and too few in the classes 1.01 to 2.00 x S. E.

TABLE 4.—*The total number of differences in yield between a variety and its theoretical check that fall within 0.5, 1.0, 1.5, etc., times standard error of a difference and the X^2 values for testing the agreement between observed number of differences and mathematical expectation.*

Class ranges	Mathematical expectation	Methods of calculating the theoretical checks	
		By av. 2 nearby checks	By grading the yield of variety on the basis of the checks
0.00–0.50 x S. E.	55.14	80	78
0.51–1.00 x S. E.	43.17	39	41
1.01–1.50 x S. E.	26.45	18	17
1.51–2.00 x S. E.	12.69	2	4
2.01–2.50 x S. E.	4.77	2	3
2.51–3.00 x S. E.	1.40	2	0
3.01–3.50 x S. E.	0.32	1	1
D/F	—	4	4
X^2	—	23.6578	19.8688

SUMMARY

1 Three uniformity trials conducted in two rice regions with different environmental conditions in the Chekiang Province, China, were carried out in this study. A different variety was used in each of the three trials. The analysis of variance was used to determine both the most desirable size and shape of plats and the efficiency of randomized distribution of replicated plats. The standard error method was used for determining both the desirability of the use of check plats as a means of correcting yields and the efficiency of a systematic distribution of replicated plats.

2. In general, the single-row plat was more efficient than any other size with but one exception, i. e., the two-row plat of the Hangchow medium-maturing variety which was approximately 9% more efficient than the single-row plat.

3. Increase in width of plat was comparatively more efficient than increase in length of row in the experiments at Hangchow, but an opposite result was obtained with the Wufu late-maturing variety.

4. In the randomized arrangement, the number of differences in yield between all possible comparisons of hypothetical varieties that fell within 0.5 times standard error, 1.0 times standard error, and so forth, was computed. A satisfactory agreement between observed numbers and mathematical expectation was obtained in the two experiments at Hangchow, but in the Wufu experiment P was less than 0.01.

5. With the systematic arrangement the deviations from mathematical expectation were too great to be explained on the basis of random sampling.

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NODULATION OF PEANUT PLANTS AS AFFECTED BY VARIETY, SHELLING OF SEED, AND DISINFECTION OF SEED[1]

J. F. DUGGAR[2]

THESE experiments were conducted in the field on Norfolk soils near Auburn, Ala. Average nodule numbers were determined at successive dates throughout three growing seasons on samples of plants of comparable age. Periods of severe drought occurred in 1930 and 1933, but rainfall was ample in 1932.

NODULATION BEHAVIOR OF SPANISH AND RUNNER PLANTS

Table 1 records the number of both total and large nodules as found at the final harvest of Spanish and runner peanuts each year. At this time the Spanish plants had reached practical maturity, but the runner plants were still growing and had a considerable portion of their nuts not fully matured.

TABLE 1.—*Average nodule numbers on non-inoculated Spanish and runner type peanut plants at final harvest, 1930, 1932, and 1933.*

Variety	Year	Average number of nodules per plant	
		Total nodules	Large nodules
Spanish........	1930	8.7	2.3
Runner........	1930	69.5	6.5
Spanish........	1932	17.5	10.1
Runner........	1932	235.5	34.8
Spanish........	1933	7.0	3.0
Runner........	1933	75.0	14.8
Spanish........	Av., 3 yrs.	11.0	5.1
Runner........	Av., 3 yrs.	126.7	18.7

Both total and large nodules on runner plants were many times more numerous than on Spanish peanut plants. This held true not only at the final date of harvest, but at every date of examination throughout the 3 years. The runner plants took a decided lead in nodulation at a rather early age and before any difference in extent of leaf surface was obvious. The later maturity and greater succulence of the runner plants during the latter part of the season seemed to offer only a partial explanation of the difference in nodulation. Such dissimilarity in nodulation is surprising in view of the fact that these are mere cultivated varieties within the same species.

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It runs parallel to differences that other investigators have found in the nodulation of certain varieties of soybeans.

In a single experiment made in 1930 and not here tabulated, unhulled seed of the two varieties were inoculated with a pure culture made from the peanut plant. Inoculation unmistakably increased the nodulation of Spanish plants, but did not obviously affect that of the runner plants. The latter, although not artificially inoculated, had many more nodules than the inoculated Spanish plants.

In the experiments with surface disinfection of seed, as reported in a later paragraph, it was found that the runner plants were more intensely nodulated even when the seed peanuts were first disinfected. This indicates that the difference in nodulation was not due to the conveyance of more or different micro-organisms on the runner seed, but was probably due to the symbiotic bacteria naturally present in these several soils being better adapted to the roots of the runner plants than to the Spanish plants.

NODULATION OF PLANTS FROM SHELLED VS. UNSHELLED SEED

Experiments were conducted in three years in which both inoculated and non-inoculated seed peanuts of the Spanish variety were employed. These were planted on unfertilized plats and on other plats supplied with 600 pounds of basic slag phosphate per acre.

When the seed were not inoculated, plants from unhulled and shelled seed, on the average, produced nearly the same number of nodules. The yields of dry nuts and average weight of entire dry plants were also practically the same from the two classes of seed.

On the other hand, when the seed were inoculated, plants from unhulled peanuts had 31 total nodules per plant as the average of five experiments, in contrast with only 18 from shelled seed, and had 11.6 large nodules against only 7.5 from shelled seed. The more intensive nodulation of plants from unhulled seed than from shelled seed, when both were inoculated in a watery suspension of pure culture made from peanut nodules, may be due to the capacity of the unhulled seed, with its greater volume and rougher surface, to convey to the soil more of the inoculum than can the smaller, smoother, shelled seed. The average yield of inoculated plants in five experiments was 11.5 grams of dry nuts per plant from unhulled seed, with their larger nodule numbers, in contrast with 9.0 grams of nuts from shelled seed. The average weight of the entire dry plant from unhulled seed was 24.5 against 19.4 grams from shelled seed.

EFFECT OF DISINFECTION OF SEED ON NODULATION OF PEANUTS

Disinfection of the surface of seed peanuts with chemicals was employed with the initial purpose of determining whether the production of nodules on plants not artificially inoculated would be increased by any nitrogen-fixing organisms conceivably carried over on the peanut hull from the harvest field to the new seedbed. The resulting data indicated that the exclusion of this possible source of these organisms

did not prevent the development of a certain number of root tubercles. Hence, the origin of such nodules as spontaneously occurred on Spanish peanuts growing in a number of experimental fields is evidently to be found in the appropriate micro-organisms naturally present in each of these soils rather than in flora adhering to the seed peanuts.

Successive counts of nodules were made throughout three summers on many hundreds of peanut plants, following planting of unhulled Spanish peanuts, both untreated and treated, with various standard disinfectants. These data, though not uniform for the several chemicals and for the various successive ages at which the plants were examined, are interpreted as showing the following general tendencies: For Semesan (1:200), to exert only at certain early stages of growth an effect apparently mildly favorable to nodulation; for copper sulfate (1:30), and boric acid (saturated solution), to be depressive to nodulation while the plants are young; for mercuric chloride (1:1000), with variations in methods of application, to be variable in effect; and for slight charring of peanut hulls with sulfuric acid, promptly followed by repeated washing, to be apparently stimulating to nodule formation up to at least the blooming stage of Spanish peanuts.

Counts in two summers to ascertain the percentage of a stand following treatments as above of unhulled Spanish peanut seed showed a general tendency for disinfectants to depress germination. The average for 2 years, taking 100 as the stand from untreated seed, was found to be 63% for the charring with sulfuric acid, promptly washed off, and 89% for mercuric chloride, also removed

SUMMARY

Without artificial inoculation, Spanish peanut plants at harvest averaged only 11 total nodules per plant in contrast with 127 on runner plants. The average number of large nodules per plant was 5 with the Spanish and 19 with the runner variety.

Under the conditions of these field experiments the runner variety, unlike the Spanish, appeared not to be benefited by artificial inoculation.

The planting of shelled in comparison with unhulled seed of Spanish peanuts, when both were without artificial inoculation, was not followed by any consistent differences in nodulation, or aggregate dry weight of nuts per plant, or total plant weight.

On the other hand, when both shelled and unhulled Spanish peanut seed were *inoculated*, plants from unhulled seed averaged significantly larger numbers of both total and large nodules and greater weight per plant of both nuts and entire plant. These advantages of unhulled seed are attributed to their carrying larger amounts of inoculum into the soil because of their greater size and rougher surface.

Soaking unhulled seed peanuts not artificially inoculated in various disinfectants tended, with most chemicals, to reduce nodule numbers and to reduce germination.

THE NUMBERS OF *RHIZOBIUM MELILOTI* AND *RHIZOBIUM TRIFOLII* IN SOILS AS INFLUENCED BY SOIL MANAGEMENT PRACTICES[1]

R. H. WALKER AND P. E. BROWN[2]

NUMEROUS investigations have shown that soil management practices and cropping systems greatly influence the general microbiological flora of soils. It seems logical, therefore, to assume that such practices would affect the numbers and activities of specific groups of organisms. That this is true in the case of two species of the root nodule bacteria of the Leguminosae, namely, *Rhizobium meliloti* and *R. trifolii*, will be pointed out in this paper.

Factors affecting the growth of the root nodule bacteria have been studied to a limited extent, but most of the investigations have dealt with the organisms when grown in pure culture or in symbiosis with the plant. While these studies have yielded valuable information, they have not indicated directly the effect of soil conditions and cropping systems on the growth and longevity of these organisms in the soil in the absence of the host.

Research on this problem has been slow to develop, primarily because of a lack of suitable methods. It has been practically impossible to determine the numbers of and to study the root nodule organisms in soils in the presence of the natural soil flora. The development of a suitable method for this purpose, however, has opened up new possibilities and the study of the root nodule bacteria in soils has begun.

HISTORICAL

Wilson (4, 5, 6)[3] has made a rather careful and extensive study of the legume bacteria population of soils. He concluded that soils may be or may become an unfavorable habitat for the various groups of legume bacteria, and that the bacteria may largely or entirely disappear from the soil. This disappearance, he concluded, goes hand in hand with increasing acidity of the soil. The bacteria do not seem to be greatly influenced by the frequency of the host in the rotation, for he found that in acid soils the addition of more bacteria resulted in the formation of a larger number of nodules per plant. In a more recent publication (7), he concluded that, although a growing crop may liberate a very large bacterial population in the soil when the nodular tissue decomposes, this population is transitory and probably does not exist for as long a period as 1 year and that the root nodule bacteria dwindle almost to extinction in certain cases.

Lochhead and Thexton (1) determined the numbers of three species of *Rhizobium* at 3- to 4-week intervals for 3 years in areas which for 20 years had been receiving no fertilizer, manure, or artificial fertilizer, respectively. *R. trifolii*, the only species with the host plant in the rotation, was present in much greater numbers than the other rhizobia, not only immediately following clover, but in later

[1]Contribution from the Department of Farm Crops and Soils, Iowa Agricultural Experiment Station, Ames, Iowa. Journal Paper J. 217, Iowa Agricultural Experiment Station. Project 406. Received for publication January 14, 1935.

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[3]Figures in parenthesis refer to "Literature Cited," p. 296.

years when the numbers had ceased to decline. Whereas quantitative differences were slight in the case of *R. trifolii*, the two fertilized soils contained noticeably higher numbers of *R. leguminosarum* (19 to 20 times) and *R. meliloti* (5 and 11 times) than did the unfertilized area.

In making recommendations concerning legume inoculation, one is continuously confronted with the lack of information to serve as a basis for his recommendations. It has been the practice, rather generally, to advocate the inoculation of legume seed if it is to be sown on land where the particular legume, or one belonging to the same cross inoculation group, has not been grown for a number of years. There appears to be no definite information available to indicate the length of time that may intervene between the growing of legume crops without the need for further inoculation. Neither has there been adequate information to indicate the effect of soil conditions on the growth and longevity of the root nodule organisms in the soil after the removal of the legume crop. It is obvious that the character and composition of the soil play a major rôle in determining the growth of these organisms after the legume crop is removed from the land. It follows, therefore, that recommendations concerning legume or soil inoculation should be based upon a complete knowledge of soil conditions, cropping history of the land, and also a knowledge of factors affecting the growth and longevity of the organisms in soils. It seems entirely possible that further research on this problem will yield information of considerable value in determining the need of a particular soil for inoculation. A knowledge of the number of these organisms in a soil will undoubtedly be of much help in this connection.

It was for the purpose of extending our information on this problem that the investigation reported here was initiated.

EXPERIMENTAL

On the Agronomy farm at Iowa State College there are available several series of plats where various fertilizer treatments have been made and different cropping systems have been followed for the past 20 years. The soils ot these plats are admirably suited to the study of factors affecting the number of root nodule bacteria in soils. Hence several of these plats have been sampled, at various times of the year, and the soils examined for *R. meliloti* and *R. trifolii*.

The samples taken for this study consisted of a composite of 16 to 20 subsamples, systematically taken over 1/10 acre plats. Only the surface 4 or 5 inches of soil were sampled. The studies were made by the method developed by Wilson (5) which is a modification of the dilution method for determining numbers of bacteria and is especially adapted to the study of the legume bacteria in soils. In general, this method consists of making several dilutions of the soil to be tested, the highest being beyond the one expected to contain the organisms to be counted. A portion of each dilution is then transferred to tumblers or jars of sterile sand to serve as inoculum. After a few days incubation sterile seed of the particular legume whose symbiont is to be studied is planted in the sand. After sufficient time has elapsed to allow for the development ot nodules on the roots of the young seedlings, usually 2 to 3 weeks, the plants are dug and the roots examined for the presence of nodules. A record is then made of the dilutions carrying the nodule bacteria and from the data thus obtained it is possible to estimate with fair degree of accuracy the minimum numbers of legume bacteria in soils.

The following relatively unimportant modifications from the procedure followed by Wilson have been adopted as a part of the routine in this work. In each instance the seed was sterilized with hydrogen peroxide according to the method

developed by Walker and Erdman (3). All dilutions were made in units of 10, and 10-cc portions of the soil suspension were used in all transfers, including the portions used to inoculate the sterile sand. The plants were grown in sand contained in 1-quart earthenware jars.

It should be made clear that the numbers of legume bacteria as reported in the tables that follow are not claimed to be the exact number in the soils examined. Rather they represent an estimation of the minimum numbers. It was pointed out above that the dilutions were made in units of 10. Hence where a soil is reported as containing 10,000 bacteria per gram it is inferred that there were at least that many present and probably more, the exact number being somewhere between 10,000 and 100,000. That this is a rather wide gap is true, but where this method is employed the large differences only and not the small ones are observable. Hence the differences observed are undoubtedly of real significance.

RESULTS

In one series of tests the numbers of *R. meliloti* and *R. trifolii* were determined in the soils of the variously treated plats of the 2- and 3-year rotation experiments at the Agronomy farm. In each of these experiments there are untreated plats; plats treated with manure and limestone; with manure, limestone, and rock phosphate; and with crop residues and limestone. The manure has been applied to the soil once in the rotation but always at the rate of 2 tons per acre per year. Limestone has been applied when needed to meet the lime requirement of the soil. Rock phosphate has been applied once in the rotation, for the first 10 years at the rate of 500 pounds per acre per year and during the last 10 years at half that amount. The crop residues consist of straw, corn stalks, and other residues and the second crop of clover when that crop is grown. The soil, which is Clarion loam, has been subjected to these treatments for the past 20 years. During that time no legume crop has grown on the plats of the 2-year rotation, but mixed red clover and alfalfa have been grown on the 3-year rotation plats every third year, with corn and oats being grown the other 2 years. During the past 10 years the legume seed has been inoculated with a pure culture of the appropriate organism before seeding.

Under the 2-year rotation there are two blocks of plats so that one of the blocks of plats is cropped to one of the crops of the rotation each year. Likewise, there are three blocks of plats in the 3-year rotation and one of the crops of the rotation is grown on one of the blocks of plats each year. In the experiments reported here soil samples were taken from the blocks of each rotation where corn and oats were being grown. The results obtained in these tests are shown in Tables 1 and 2.

The data of these tables show rather definitely the effects of the soil treatments and the growth of legume plants upon the numbers of *R. meliloti* and *R. trifolii* in this soil. It may be observed that in every instance with one exception, the application of manure and limestone to this soil increased the number of these organisms. This increase was 10-fold in most instances and in some cases even greater.

TABLE 1.—*Numbers of root nodule bacteria per gram of soil in the 2- and 3-year rotation plats, 1934.*

Plat No.	Soil treatment	pH	R. meliloti			R. trifolii		
			May 1	June 14	Sept. 20	May 1	June 14	Sept. 20
			2-year Rotation, Corn and Oats					
811	Check	6.06*	100	10	100	100	10	100
812	M + L	7.23	1,000	100	1,000	1,000	100	1,000
813	M + L + RP	7.21	1,000	1,000	10,000	1,000	1,000	10,000
814	CR + L	7.23	100†	1,000	1,000	10,000†	1,000	1,000
			3-year Rotation, Corn, Oats, and Mixed Red Clover and Alfalfa‡					
829	Check	5.79	1,000	100	100	10,000	100	100
830	M + L	6.84	10,000	1,000	1,000	10,000	1,000	1,000
831	M + L + RP	6.98	100,000	10,000	100,000	10,000	10,000	100,000
832	CR + L	7.05	10,000	1,000	1,000	10,000	1,000	1,000

*The pH determinations were made on the samples taken Sept. 20.
†Results doubtful.
‡Red clover and alfalfa were grown on the 3-year rotation plats the year previous to sampling the soil.

TABLE 2.—*Numbers of root nodule bacteria per gram of soil in the 2- and 3-year rotation plats, May 22 and Oct. 8, 1934.**

Plat No.	Soil treatment	pH	R. meliloti		R. trifolii	
			May 22	Oct. 8	May 22	Oct. 8
			2-year Rotation, Corn and Oats			
805	Check	6.11	10	10	10	10
806	M + L	6.91	1,000	100	1,000	100
807	M + L + RP	7.08	100	1,000	1,000	1,000
808	CR + L	6.94	1,000	100	1,000	100
			3-year Rotation, Corn, Oats, and Red Clover and Alfalfa			
817	Check	5.87	100	10	100	10
818	M + L	7.11	10,000	100	10,000	100
819	M + L + RP	6.94	100,000	1,000	100,000	1,000
820	CR + L	7.04	10,000	100	100,000	100

*Oats were grown on all plats in 1934. Red clover and alfalfa were sown with the oats in the 3-year rotation plats but did not grow because of the dry weather.

There was about the same number of these organisms in the soil treated with crop residues and limestone as in that treated with manure and limestone. There is some indication that the limestone is the predominating factor responsible for the increase in numbers of organisms in the soils in these two plats over those found in the untreated soils in the check plats, but the organic matter factor is not isolated from the other, hence it must be given some credit for the increase. Unfortunately, soils treated with limestone only and with organic matter only were not available in this particular group of plats. From a practical standpoint, however, this is not important, for on this type of soil it is recommended that both limestone and manure treatments be made for the best growth of general farm crops,

including the legumes. Hence, under practical conditions as recommended, the combined effect of the two treatments would certainly increase the numbers of root nodule bacteria in the soil.

The application of rock phosphate to this soil in addition to the manure and limestone was responsible for a still further increase in numbers of root nodule bacteria. This increase was as large in most instances as that effected by the manure and limestone, and in some cases it was even larger. This soil, presumably, is somewhat deficient in available phosphate for the growth of higher plants, as it responds fairly well to applications of this fertilizer. This is shown in the yields of crops produced on these plats (2). Apparently, also, this soil is deficient in phosphate for the growth of the alfalfa and red clover root nodule bacteria and is a much better medium for growth after the application of the rock phosphate. Whether the application of phosphate alone to this soil would result in these large increases in numbers of root nodule bacteria is not known. It is very probable, however, that the combination of organic matter, limestone, and phosphate is necessary to effect the large increases in numbers shown by the data.

It may be contended that the larger number of root nodule bacteria in the soil is a result of a better development of the legume crop. This is undoubtedly true in many instances, and especially where the legume crop is being grown on the land frequently in the rotation. It will be observed, however, that the same effect of the soil treatments appeared in the soils of the 2-year rotation where no leguminous host plant has been on the land for the past 20 years. The growing of a legume crop, however, does influence the number of root nodule bacteria in the soil. This is shown by the data of Tables 1 and 2. In most instances there were about 10 times as many root nodule bacteria in the 3-year rotation soils where the respective leguminous host plant has been grown as in the 2-year rotation soils where the host plant has not been grown. This increase in numbers resulting from the growth of the host plant on the land is not as large, however, as one might expect. It appears that the condition of the soil with reference to organic matter, lime, and phosphate has a much larger influence on the numbers of these organisms in this soil than does the frequency of growth of the host plant. These observations are in agreement with those of Wilson (3, 7).

There were approximately the same number of *R. meliloti* and *R. trifolii* in the soil of these variously treated plats. This is true for the soils of the 3-year rotation plats where both alfalfa and red clover are grown and also for the soils of the 2-year rotation plats where neither legume crop has been grown.

In another series of tests the numbers of *R. meliloti* and *R. trifolii* were determined in the soils of the 5-year rotation plats. The rotation followed on these plats is corn, oats, red clover, winter wheat, and alfalfa. During the past 5 years it has been the practice to sow some alfalfa with the red clover and also to sow some hubam sweet clover in with the winter wheat. The alfalfa is allowed to remain on the land for 5 years. Hence, alfalfa and red clover have been grown on these plats frequently and there has been ample opportunity for

the soil of all the plats to become well supplied with the respective root nodule bacteria. The results obtained upon analysis of the soils from one block of plats in this rotation are shown in Table 3. Corn was grown on this land in 1933 previous to taking the first set of samples. The two sets of samples taken in the spring were obtained during the time the land was being prepared for seeding oats and the legume crops.

TABLE 3.—*Numbers of root nodule bacteria per gram of soil in the 5-year rotation plats in the fall of 1933 and spring of 1934.**

Plat No.	Soil treatment	pH	*R. meliloti*			*R. trifolii*		
			Oct. 25	Mar. 20	April 2	Oct. 25	Mar. 20	April 2
1012	Check	5.72	10	10	10	1,000	1,000	10
1013	Manure	5.72	100	100	1,000	1,000	1,000	100
1014	M + lime	6.85	10,000	10,000	100,000	10,000	10,000	100,000
1015	M + L + RP	6.87	100,000	10,000	1,000	10,000	10,000	1,000
1017	Check	5.84	100	100	100	1,000	10,000	100
1019	CR + lime	6.77	10,000	1,000	10,000	10,000	1,000	10,000
1020	CR + L + RP	6.87	10,000	100,000	10,000	10,000	100,000	10,000

*Cropping system: 1930, oats + red clover and alfalfa; 1931, red clover and alfalfa; 1932, wheat + hubam sweet clover; 1933, corn.

These data indicate the large extent to which the numbers of these organisms were increased by the application of manure, limestone, and rock phosphate to this soil. The most striking example is shown on October 25 in the case of *R. meliloti* where the number was increased from 10 per gram in the untreated soil to 100,000 in the soil treated with manure, limestone, and rock phosphate. This is certainly an increase of real significance, and a large influence on the nodulation of a legume crop grown on these soils might be expected. Although the increases in numbers effected by the various soil treatments were not so pronounced or regular at other times, the data as a whole indicate the same general effect. The importance of maintaining the soil in a high state of fertility in order to support a relatively large number of root nodule bacteria in the soil is emphasized.

In Table 4 data obtained in other tests on plats in the 5-year rotation are presented. Corn had been grown on the 1000 series of plats during the season prior to sampling and a year had elapsed since alfalfa and red clover had been grown on the land. Alfalfa had been grown on the 900 series of plats for 5 years and until about a month before the samples were taken. At the time of sampling this series of plats numerous undecayed alfalfa roots were present in the soil.

The data of Table 4 show the same general effects of the various soil treatments on the numbers of alfalfa and red clover root nodule bacteria as were shown by the data from the 2- and 3-year rotation soils and also the other series of soils under the 5-year rotation. An increase in numbers of root nodule bacteria was brought about by each additional soil treatment in most instances. The most striking example of this is shown in the numbers of *R. meliloti* in the soils of the 900 series. In that case there was an increase from 1,000 per gram

of untreated soil to 1,000,000 per gram of the soil treated with manure, limestone, and rock phosphate. The numbers of *R. trifolii* did not appear to be affected differentially by the various soil treatments in the 900 series, but there was a 10-fold increase in each of the treated soils over the untreated soil of the check plat.

TABLE 4.—*Numbers of root nodule bacteria per gram of soil in the 5-year rotation plats.**

Plat No.	Soil treatment	pH	*R. meliloti*	*R. trifolii*
	Series 1000, Samples Taken Nov. 9, 1934			
1024........	Check	6.22	100	100
1025........	Manure	6.41	100	100
1026........	M + lime	7.48	1,000	1,000
1027........	M + L + RP	7.74	10,000	10,000
1031........	CR + L	8.11	1,000	1,000
	Series 900, Samples Taken Nov. 14, 1934			
924........	Check	5.77	1,000	1,000
925........	Manure	5.81	10,000	10,000
926........	M + lime	6.73	100,000	10,000
927........	M + L + RP	6.81	1,000,000	10,000
931........	CR + L	7.34	100,000	10,000

*Cropping systems: Series 1000, 1931, oats + clover and alfalfa; 1932, red clover and alfalfa; 1933, wheat + hubam sweet clover; 1934, corn. Series 900, 1926, corn; 1927, oats; 1928, clover; 1929, wheat; 1930–34, alfalfa. The alfalfa of this series was plowed up within a month prior to sampling.

It may also be observed from the data of Table 4 that there were 10 to 100 times as many alfalfa root nodule bacteria in the soils of the 900 series as in the similarly treated soils of the 1000 series of plats. This undoubtedly was due to the fact that alfalfa was growing on the soils of the 900 series immediately preceding the time of sampling of the soils, whereas it had been over a year since it had been grown on the soils of the 1000 series. It is very likely that soils in the 1000 series had decreased markedly in alfalfa root nodule bacteria since the alfalfa crop had been plowed under. These results agree to a certain extent with the conclusions drawn by Wilson concerning the soybean root nodule bacteria.

It is obvious, from the results previously presented, that the rate of disappearance of these organisms depends largely upon the character of the soil in which they occur. On the other hand, there was a markedly smaller number of these organisms in the soils where alfalfa had not grown for a year, even though the soil was apparently in good condition for the growth of the bacteria. The pH of the soil of plat 1027, for instance, was definitely on the basic side of the optimum, and the soil had also received applications of organic matter and phosphate fertilizer. Obviously, this soil, even with the favorable treatments, was not as suitable a habitat for the organisms in the absence of its symbiont as in its presence.

SUMMARY AND CONCLUSIONS

1. Wilson's modification of the dilution method was used in determining the approximate numbers of *R. meliloti* and *R. trifolii* in variously treated soils at the Agronomy farm at Iowa State College.

2. It was found that, in general, the number of these root nodule bacteria in soils depends upon the previous cropping history of the land, and also upon the fertilizer treatments that have been made to the soil.

3. Larger numbers of both species were found in the soil of the 3-year rotation plats where mixed red clover and alfalfa are grown every third year than in the soil of the 2-year rotation plats where legume crops have not grown for over 20 years.

4. Larger numbers of *R. meliloti* were also present in soil where alfalfa had been plowed up a month previous to sampling than where alfalfa had not been grown on the land for over a year.

5. Applications of crop residues, manure, limestone, and rock phosphate each enabled the soil to support a larger number of alfalfa and red clover root nodule bacteria. The largest numbers of these organisms occurred in soils receiving combinations of these treatments.

6. It appears that the condition of the soil with reference to organic matter, lime, and phosphate has a much larger influence on the numbers of these organisms in this soil than does the frequency of growth of the host plant.

7. It is suggested that recommendations for soil or seed inoculation should be based, not only upon a knowledge of the cropping system to which the soil has been subjected, but also upon a knowledge of the soil management practices that have been followed.

8. As more is learned of the factors affecting the growth of the root nodule bacteria in soils and also of the numbers required in the soil for the maximum benefit to the host, it is entirely possible that the determination of their numbers will serve as a better means for determining the need for inoculation than we now have.

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DIVERGENT INFLUENCE OF DEGREE OF BASE SATURATION OF SOILS ON THE AVAILABILITY OF NATIVE, SOLUBLE, AND ROCK PHOSPHATES[1]

R. L. Cook[2]

It is known that the native and soluble phosphates applied as fertilizers, remain more readily available when the pH of the soil is about 6.5 or higher (barring a great excess of $CaCO_3$), and that rock phosphate is usually more effective when the soil is at least slightly acid. In certain cases, lime with rock phosphate has depressed yields as compared to rock phosphate alone, while the opposite result has been obtained with lime and superphosphate. This investigation was undertaken in an attempt to explain more fully the reasons for these divergent effects of base saturation or soil reaction on the ability of plants to obtain phosphorus from different sources.

The influence of base saturation or soil reaction on the availability of native phosphates and applied rock or soluble phosphates has been studied quite extensively, and the following are only a few references to earlier work.

HISTORICAL

Kossowitsch (7)[3] and Prianischnikow (9) showed in pot and field studies that rock phosphate is more effective as a source of phosphorus on acid than on non-acid soils, especially the calcareous ones.

Ford (2), studying the soils of the Kentucky Station experimental fields, found that lime markedly reduced the rate of transformation of the rock phosphate to other forms.

Prianischnikow (8), Truog (12), and others have classified certain plants on the basis of their feeding power for the phosphorus of rock phosphate. Truog suggests that the solution of rock phosphate in the soil through its reaction with carbonic acid should be considered a balanced reaction similar to the following: $Ca_3(PO_4)_2 + 2H_2CO_3 \rightleftharpoons Ca_2H_2(PO_4)_2 + Ca(HCO_3)_2$. Both of the products formed are soluble and, according to the law of mass action and chemical equilibrium, must be removed from solution in proper proportion if the reaction is to continue indefinitely. Truog holds that plants which require large amounts of calcium remove the soluble calcium salts produced in this reaction at a rate sufficiently rapid to allow the solution of the phosphate to continue. As a consequence, they are strong feeders on rock phosphate. Plants which are low in calcium quickly allow an accumulation of $Ca(HCO_3)_2$ to a point of saturation, after which, further solution of the phosphate is very slow. As a consequence, these plants are weak feeders on

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[3]Figures in parenthesis refer to "Literature Cited," p. 311.

rock phosphate. One of the purposes of the present investigation was to ascertain whether or not the removal of calcium from the soil solution through base exchange reactions would make it possible for plants low in calcium to feed effectively on rock phosphate.

For a detailed review of the subject of plant feeding, the reader is referred to Thomas (11).

Teakle (10) showed that with varying degrees of soil acidity different cations are responsible for the removal of phosphate from the soil solution. Ford (3) emphasizes the fact that phosphates fixed as calcium phosphate are readily available while those fixed as ferric phosphate are less available. His work shows that fixation in difficultly soluble form is due to the hydrated iron oxides, such as goethite, which form very difficultly soluble basic iron phosphates.

BASE SATURATION AND AVAILABILITY OF ROCK PHOSPHATE TO PLANTS

The first part of this investigation deals with the influence of hydrogen- and calcium-saturated inorganic and organic base exchange material on the availability of rock and tricalcium phosphate to plants in quartz sand cultures. It was thought that if some hydrogen-saturated exchange material was placed in the system, it would take up the soluble calcium, and thus plants which are weak feeders would be able to obtain phosphorus more advantageously from the rock phosphate.

PREPARATION OF EXCHANGE MATERIAL

From bentonite.—Since, as shown by Kerr (6), bentonite has exchange properties similar to those of soils, work was started with this material which was prepared as follows: The bentonite, pulverized to 40-mesh, was dispersed in a large quantity of water; and after standing over night, the suspension was siphoned off and evaporated to dryness. To remove carbonates, the residue, after pulverizing again to 40-mesh, was digested for 48 to 60 hours in a solution of N $NH_4C_2H_3O_2$ maintained with HNO_3 at a pH of 5.5. The $NH_4C_2H_3O_2$ prevented the material from swelling and becoming difficult to handle. When digestion was complete, the mixture was leached on a Buechner funnel with a solution, 0.5 N with respect to NH_4NO_3, and 0.05 N with respect to HNO_3, until free of calcium, and then with distilled water until deflocculation caused the leaching to become very slow. The dried material was ground to pass a 100-mesh sieve. The product, saturated partly with the H-ion and partly with the NH_4-ion, was placed in shallow nickel pans and heated to 450° C in a muffle furnace for 48 hours. This treatment removed all but traces of the replaceable ammonia, leaving the material saturated with hydrogen. Previous work had shown that heating to 450° C does not alter the exchange capacity of this material. The heating also served to break down any free NH_4NO_3 and volatilize any remaining nitric acid.

Calcium-saturated exchange material from bentonite was prepared by treating material in the manner just described up to the point of heating, when, in place of heating, it was digested over night on the steam plate with a solution 0.5 N with respect to both $(NH_4)_2CO_3$ and $NH_4C_2H_3O_2$, filtered, and washed with 0.5 N $NH_4C_2H_3O_2$ until free of $(NH_4)_2CO_3$. Next it was saturated with calcium by leaching with N $CaCl_2$, and washed with distilled water and then alcohol until free of chlorides. The material was then dried and ground to 100-mesh.

From soils.—Hydrogen-saturated exchange materials from organic and inorganic soils were prepared by leaching the soils with 0.05 N HNO_3 until calcium could no longer be detected in the filtrates. This required from 24 to 48 hours of leaching on a Buechner funnel, using suction only when necessary to maintain a slow rate of leaching. The excess acid was removed by washing with water until the filtrate became cloudy, which condition indicated that enough acid had been removed to allow deflocculation of the colloids. The soil was then dispersed in a large volume of water, and after standing over night, the suspension was siphoned off, evaporated to dryness, and the residue ground to 100-mesh.

The exchange capacity of the materials was determined as follows: A 0.5-gram sample in 200 cc of a solution 0.5 N with respect to both $(NH_4)_2CO_3$ and $NH_4C_2H_3O_2$ was digested on a steam plate for 2 hours. The suspension was then filtered, and the material washed with 0.5 N $NH_4C_2H_3O_2$ until all carbonate was removed. The sample was leached with 300 cc of N $CaCl_2$ and then with alcohol (80% by volume) until free of chlorides. The calcium was then displaced by leaching with 300 cc of N $NH_4C_2H_3O_2$, and determined in the usual way.

PLAN OF POT CULTURES

Oats, corn, millet, and buckwheat were grown in a greenhouse in 2-gallon glazed earthenware jars, each filled with 10 kg of white quartz sand. The jars had holes for drainage. The sand contained 6 p. p. m. of phosphorus soluble in 0.002 N sulfuric acid, and 0.1 millequivalent of calcium as $CaCO_3$ per 100 grams. Phosphates as follows were used: The rock phosphate was 300-mesh material containing 34.53% P_2O_5 and 29.16% calcium. It was applied at the rate of 500 pounds per acre. The soluble phosphate was C. P. monocalcium phosphate, and was applied in an amount equivalent to 500 pounds per acre of 20% superphosphate. The tricalcium phosphate was C. P. material treated to reduce solubility in water by heating to 450° C for 24 hours and then leaching with distilled water until the leachate became practically free of phosphorus. Before this treatment, the material contained considerable water-soluble phosphorus.

All exchange materials and phosphorus-carrying compounds were thoroughly mixed with the dry sand. Enough seeds were planted to permit selection of sturdy, uniformly spaced plants, 3 in the case of corn and 15 of the others. A moisture content of about 10% was maintained. Shortly after the plants appeared above the surface, each pot received the following nutrient salts dissolved in 500 cc of water:

KNO_3	1.0 gram	$MnCl_2$	0.005 gram
$Ca(NO_3)_2 \cdot 4H_2O$	0.5 gram	NaI	0.001 gram
$MgSO_4 \cdot 7H_2O$	0.25 gram	$FeCl_3 \cdot 6H_2O$	0.014 gram

In most cases the crops were harvested after 4 to 6 weeks of growth. One series of oats was allowed to mature. The tissue was placed in paper bags, dried in a steam oven at about 80°C, and then weighed.

YIELDS WITH BENTONITE EXCHANGE MATERIAL

The weights of the various crops produced with and without exchange material from bentonite are given in Table 1.

Oats.—The results show that rock phosphate, without and with calcium-saturated exchange material, produced no larger yields of oats than the controls (no phosphate), but with hydrogen-saturated

TABLE 1.—*The effect of hydrogen- and calcium-saturated exchange material from bentonite on the availability of rock phosphate and tricalcium phosphate as measured by growth of various crops in quartz cultures.*

Phosphate and exchange material additions to cultures*	pH of culture	Yield in grams (average of two pots)														
		Oats					Corn				Millet		Buckwheat			
		Series 1			Series 2		Series 1		Series 2				Series 1		Series 2	
		Grain in tops %	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops
Control, no Phos. or Ex. Ma.	8.0	23.1	1.4	4.4	1.7	3.5	3.5	7.6	2.6	3.9	0.5	0.8	0.8	8.5	1.0	5.9
H. Ex. Ma., 100 grams	6.4	22.6	1.2	4.0	—	—	3.7	6.8	—	—	—	—	1.0	9.7	—	—
Rock Phos.	8.0	29.7	1.2	5.8	1.6	3.9	6.8	16.3	4.1	4.1	0.3	0.8	1.6	12.6	1.3	9.0
Rock Phos. + 100 grams H. Ex. Ma.	6.4	46.3	4.2	20.9	2.5	10.1	9.6	27.4	10.4	26.6	2.9	10.2	0.8	9.5	1.0	9.0
Rock Phos. + 200 grams H. Ex. Ma.	5.8	44.3	3.7	21.0	—	—	—	—	—	—	—	—	—	—	—	—
Rock Phos. + 100 grams Ca. Ex. Ma.	8.0	—	—	—	2.1	3.6	—	—	3.0	5.4	—	—	—	—	—	—
$Ca_3(PO_4)_2$	8.0	—	—	—	—	—	—	—	—	—	—	—	—	—	1.1	9.6
$Ca_3(PO_4)_2$ + 100 grams H. Ex. Ma.	6.4	—	—	—	—	—	—	—	—	—	—	—	—	—	1.2	10.5
$CaH_4(PO_4)_2.H_2O$	8.0	36.9	5.1	21.7	—	—	8.6	25.7	—	—	4.1	11.3	1.7	12.3	1.0	10.9

*H. Ex. Ma. = Hydrogen-saturated exchange material from bentonite; Rock Phos. = Rock phosphate; Ca. Ex. Ma. = Calcium saturated exchange material from bentonite. Phosphate applications on the acre basis were 500 pounds of rock phosphate, an equivalent amount of $Ca_3(PO_4)_2$, and $CaH_4(PO_4)_2.H_2O$ equivalent to 500 pounds of 20% superphosphate. The exchange material varied in exchange capacity from 82 to 100 M. E. per 100 grams.

exchange material from bentonite it produced as well as the soluble phosphate. Increasing the amount of exchange material from 100 to 200 grams per pot produced no additional increases in yield. Fig. 1 shows the growths produced in the first oats series.

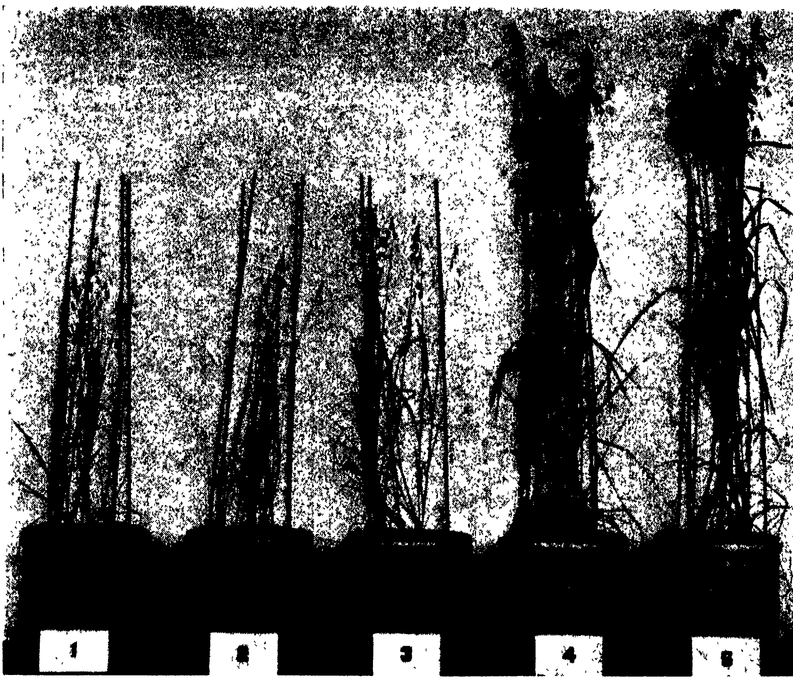

FIG. 1.—The effect of hydrogen-saturated exchange material from bentonite on the availability of rock phosphate to oats.

1, control, no phosphate or exchange material; 2, exchange material, 100 grams per pot; 3, rock phosphate, 500 pounds per acre; 4, rock phosphate, 500 pounds per acre plus exchange material, 100 grams per pot; 5, monocalcium phosphate equivalent to 500 pounds of 20% superphosphate per acre.

It was desired in the case of oats and buckwheat to save the sand for further work, so the roots could not be conveniently washed out, but were screened out after drying, and this caused some loss and inconsistencies in weights.

Buckwheat.—The results show that buckwheat, a crop which, according to Truog (12), contains over six times as much calcium as does oats, can feed almost as well on rock phosphate as upon soluble phosphate, and that, in the first series, instead of increasing the yields, the hydrogen-saturated base exchange material very noticeably depressed them. It was thought that this injurious effect might be due to the liberation of fluorine from the rock phosphate, and in order to test this possibility some of the buckwheat tissue was analyzed for fluorine, giving results as follows:

Phosphate and exchange material additions to cultures	Fluorine in buckwheat tissue %
Control	0 00682
Rock phosphate	0 02270
Rock Phosphate plus 100 grams H saturated exchange material	0 02150
$CaH_4(PO_4)_2 \cdot H_2O$	0 00319

FIG 2 —The effect of hydrogen- and calcium-saturated exchange material from bentonite on the availability of rock phosphate to corn

1, control no phosphate or exchange material, 2 rock phosphate, 500 pounds per acre, 3 rock phosphate, 500 pounds per acre, plus hydrogen-saturated exchange material, 100 grams per pot, 4, rock phosphate, 500 pounds per acre plus calcium saturated exchange material, 100 grams per pot

These data show that the plants grown with exchange material contained no more fluorine than those grown without it Furthermore, in another buckwheat test including both tricalcium and rock phosphate, this deleterious effect was absent, and the exchange material caused slight, although not significant, increases in yield with both forms of phosphate

Corn —On the basis of its calcium content and inability to feed on rock phosphate, corn has been placed by Truog (12) in the same class with oats The results clearly indicate that the availability of the rock phosphate to this crop was greatly raised by the hydrogen-saturated exchange material Fig 2 shows the relative growths of the plants in the second series 41 days after planting

Millet.—The data show millet, which is low in calcium, to be exactly like oats and corn as regards its response to the presence of hydrogen-saturated base exchange material.

ANALYSES OF OATS AND BUCKWHEAT

In order to determine more positively if the influence of base saturation on growth was due to phosphorus availability, chemical analyses were made of oats and buckwheat. The results are presented in Table 2.

Oats.—The data show conclusively that hydrogen-saturated exchange material from bentonite made it possible for oats to absorb much more phosphorus from rock phosphate. In the first series, the plants feeding on rock phosphate without exchange material contained only 1.65 mgm of phosphorus per culture, while those which were treated with rock phosphate and 100 grams of hydrogen-saturated exchange material contained 23.84 mgm per culture, over 14 times as much. On the other hand, the calcium-saturated exchange material lowered the percentage of phosphorus and raised that of calcium in the second oats series. In this same test the exchange material saturated with hydrogen caused the plants to absorb 11.7 times as much phosphorus as from rock phosphate alone and 12.7 times as much as from rock phosphate plus calcium-saturated exchange material.

Buckwheat.—This crop fed very effectively upon rock phosphate alone and the exchange material made little difference in the phosphorus content of the first series but did raise it markedly in the second. In contrast to oats, the buckwheat in the first series absorbed almost normal amounts of phosphorus from rock phosphate alone and was not benefited through the addition of the hydrogen-saturated exchange material.

RESULTS WITH ORGANIC SOIL EXCHANGE MATERIAL

It was deemed advisable to check the preceding results by the use of exchange material from actual soils, both organic and inorganic. Some organic exchange material was separated from a sample of rifle peat according to the methods previously described, and used in pot cultures of corn and millet. The results, presented in Table 3, show that this exchange material has exactly the same influence on the availability of rock phosphate as that from bentonite. When no exchange material was present, these crops were unable to feed effectively on rock phosphate; but with an application of only 10 grams of the hydrogen-saturated exchange material, the rock phosphate became almost as available as the monocalcium phosphate. Fig. 3 shows the appearance of millet 38 days after planting.

The total phosphorus content of the millet reported in Table 3 shows that the increased yields are correlated with an increased availability of the rock phosphate. The plants grown with rock phosphate and 10 grams of exchange material contained almost seven times as much phosphorus as those grown with rock phosphate alone.

TABLE 2.—*The effect of hydrogen- and calcium-saturated exchange material from bentonite on the phosphorus and calcium contents of the oats and buckwheat plants referred to in Table 1; data averages from duplicate pots.*

Phosphate and exchange material additions to cultures*	Phosphorus content									Calcium content of oats		
	Oats					Buckwheat						
	Series 1			Series 2		Series 1		Series 2		Series 1		Series 2
	Straw %	Grain %	Tops total per pot, mgm.	Tops %	Tops total per pot, mgm.	Tops %	Tops total per pot, mgm.	Tops %	Tops total per pot, mgm.	Straw %	Grain %	Tops %
Control, no Phos. or Ex. Ma.	0.010	0.054	0.80	0.042	1.41	0.209	17.76	0.100	5.90	0.452	0.283	0.438
H. Ex. Ma., 100 gm	0.015	0.128	1.59	—	—	—	—	—	—	0.407	0.280	—
Rock Phos.	0.008	0.078	1.65	0.046	1.77	0.535	67.40	0.344	30.78	0.573	0.157	0.397
Rock Phos. + 100 grams H. Ex. Ma.	0.051	0.188	23.84	0.206	20.70	0.577	54.81	0.612	55.08	0.483	0.175	0.372
Rock Phos. + 200 gm. H. Ex. Ma.	0.079	0.172	25.20	—	—	—	—	—	—	0.316	0.127	—
Rock Phos. + 100 gm. Ca. Ex. Ma.	—	—	—	0.045	1.62	—	—	—	—	—	—	0.442
$CaH_4(PO_4)_2.H_2O$	0.140	0.177	33.30	—	—	0.705	86.70	0.550	59.95	0.591	0.262	—

*See Table 1 for abbreviations.

TABLE 3.—*The effect of hydrogen-saturated exchange material from an organic soil on the availability of rock phosphate to corn and millet in quartz cultures as measured by growth and phosphorus content.*

Phosphate and exchange material additions to cultures*	Reaction of culture, pH	Corn yield (average of two pots)		Millet			
				Yield (average of two pots)		Phosphorus content of tops	
		Roots, grams	Tops, grams	Roots, grams	Tops, grams	%	mgm.
Control, no Phos. or Ex. Ma.†	8 0	4.1	4.7	1 6	1.7	0.087	1.48
Ex. Ma., 5 gm.	6.5	3.6	4 9	1 6	1.6	0.137	2.19
Rock Phos. .	8.0	4.5	5.1	1 7	1 9	0.119	2.26
Rock Phos. + 5 gm. Ex Ma	6 5	7 7	8 1	2.1	2.6	0.169	4.39
Rock Phos. + 10 gm. Ex. Ma	6.0	9.6	19 7	4 4	6 9	0.219	15.11
$CaH_4(PO_4)_2.H_2O$	8 0	10.7	24.7	5 7	9 1	0 406	36.95

*Phosphate applications on the acre basis were 500 pounds of rock phosphate and monocalcium phosphate equivalent to 500 pounds of 20% superphosphate The exchange capacity of the exchange material was 211 M E per 100 grams

†See Table 1 for abbreviations

FIG. 3.—The effect of hydrogen-saturated exchange material from an organic soil on the availability of rock phosphate to millet.

1, control, no phosphate or exchange material; 2, exchange material, 5 grams per pot; 3, rock phosphate, 500 pounds per acre; 4, rock phosphate, 500 pounds per acre, plus exchange material, 5 grams per pot; 5, rock phosphate, 500 pounds per acre, plus exchange material, 10 grams per pot; 6, monocalcium phosphate equivalent to 500 pounds of 20% superphosphate per acre.

YIELDS WITH INORGANIC SOIL EXCHANGE MATERIAL

Inorganic soil exchange material was separated in the manner previously described from the subsoil of three Wisconsin soils, Miami silt loam, Superior clay, and Colby silt loam, and used in pot cultures.

The results with millet, recorded in Table 4, show that exchange material from the first two of these soils gave results similar to those obtained with exchange material from bentonite, although the results are not so striking, due, probably in part, to the lower exchange capacity of the material from the soils. The exchange material from the other soil, Colby silt loam, seemed to have a toxic effect both with and without rock phosphate. The leaves of oats turned white soon after germination, and corn and millet plants made less growth than without exchange material. Because the appearance of the plants showed clearly the presence of some extremely toxic substance, the results with material from this soil are not recorded.

TABLE 4.—*The effect of hydrogen-saturated inorganic exchange material from soils on the availability of rock phosphate as measured by growth of millet in quartz cultures.*

Phosphate and exchange material additions to cultures*	Reaction of culture, pH	Yield (average of two pots)	
		Roots, grams	Tops, grams
Control, no Phos. or Ex. Ma.†	8.0	0.50	0.75
Rock Phos	8.0	0.30	0.80
Rock Phos. + 50 gm. Miami Si. Lo. Ex. Ma	6.0	0.40	1.25
Rock Phos. + 50 gm. Superior Cl. Ex. Ma	7.0	0.85	2.25
Rock Phos. + 100 gm. Superior Cl. Ex. Ma	6.5	1.95	3.75
$CaH_4(PO_4)_2.H_2O$	8.0	4.05	11.25

*The exchange capacity of the Miami silt loam exchange material was 48 M. E. per 100 grams; that of Superior clay 36 M. E. Phosphate applications on the acre basis were 500 pounds of rock phosphate and $CaH_4(PO_4)_2.H_2O$ equivalent to 500 pounds of 20% superphosphate.
†See Table 1 for abbreviations.

Inasmuch as exchange material from bentonite, one organic soil, and two inorganic soils gave similar results with millet, and since millet, corn, and oats reacted in the same way to the influence of exchange material from bentonite, it seems safe to assume that all of these crops would behave similarly with actual soil exchange materials, provided such materials did not contain toxic substances.

DISCUSSION

The data show conclusively that when hydrogen-saturated exchange material is added to sand cultures, rock phosphate is made much more available to certain crops. This fact is manifested by greatly increased growth and amount of phosphorus absorbed. This is in accord with the law of mass action and chemical equilibrium as is also the ineffectiveness of the calcium-saturated exchange material.

The plant roots are continually giving off carbonic acid which reacts with the rock phosphate, producing soluble phosphate and calcium bicarbonate. Both of these products must be removed from solution if the reaction is to continue. Crops such as oats, corn, and millet take up a higher proportion of phosphorus to calcium than exists in rock phosphate. As a result, the calcium bicarbonate gradu-

ally accumulates, equilibrium is established, and the further formation of soluble phosphate is suppressed. The introduction of hydrogen-saturated exchange material into the system provides for the removal of calcium from solution and thus allows the reaction between rock phosphate and carbonic acid to continue and supply the plants with phosphorus. This explains why rock phosphate gives better returns on acid than on calcareous soils.

Plants which use large quantities of calcium feed effectively on rock phosphate because they absorb calcium so rapidly that it does not accumulate as the bicarbonate and slow up the reaction between rock phosphate and carbonic acid. Accordingly, hydrogen-saturated exchange material should be less beneficial to such plants. The results obtained with buckwheat show this to be true.

BASE SATURATION AND AVAILABILITY OF SOIL PHOSPHORUS

The second part of this investigation deals with the effect of increasing the degree of base saturation of 13 Michigan soils by liming on the subsequent availability of the native and applied soluble phosphates. Readily available phosphorus was determined by the Truog (13) method.

TESTS WITH CALCIUM CARBONATE

In the tests with $CaCO_3$, 5 of the 13 soils were used. Large samples (8 kilos) of each soil were weighed out in quadruplicate. Two of the samples were then limed while the other two were not, and one each of the limed and unlimed samples were then phosphated while the other two were left unphosphated. In liming, sufficient 300-mesh calcium carbonate (finely ground limestone) was applied to raise the pH above 6.5, the point above which as shown by Gaarder (4), calcium and magnesium phosphates do not readily decompose. After thoroughly mixing the calcium carbonate with the soils, monocalcium phosphate was applied in solution to the portions to be phosphated, at the rates indicated in Table 5. The rate of application was increased with increasing power of the soils to fix phosphorus in difficultly available forms, as determined by the method outlined by Heck (5). In order to speed up whatever reactions might take place, all cultures during the next 20 days were alternately wetted to optimum moisture and dried at room temperatures 10 times, mixing thoroughly each time. At the end of this period available phosphorus was determined, extreme care being taken to get representative samples. The results are reported in Table 5.

TESTS WITH CALCIUM HYDROXIDE

In the first tests with $Ca(OH)_2$, small samples (0.5 gram of 40-mesh soil) of five soils were weighed out in quadruplicate. Two samples of each soil were limed while two were left unlimed. One of the limed and one of the unlimed samples were phosphated while the other two were not. The samples to be limed were treated with $Ca(OH)_2$ as lime water at the rate of 10 tons per acre. Unlimed samples were treated with an equal volume of distilled water. After standing over

night the samples were dried on a steam plate. Phosphorus as phosphoric acid was then applied to the portions to be phosphated. The results are reported in Table 5.

TABLE 5.—*The influence of additions of $CaCO_3$ and $Ca(OH)_2$ to Michigan soils on the availability of native phosphorus and that applied as monocalcium phosphate and phosphoric acid.*

Type of soil	Tons per acre of lime applied to limed portions	Pounds per acre of phosphorus applied to phosphated portions	Reaction of soil, pH		Pounds of available phosphorus per acre in soils			
					Unphosphated		Phosphated	
			Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
8-kg Samples Treated with $CaCO_3$, Wetted and Dried 10 Times During 20 Days								
Coloma sand....	2	43.5	6.30	7.5	41.6	49.6	58.8	64.8
Fox sandy loam.	4	43.5	5.50	7.2	30.0	40.0	44.0	54.4
Fox sandy loam.	5	87.0	4.30	6.8	35.6	41.0	81.6	97.0
Miami silt loam.	4	43.5	5.50	7.3	19.2	20.0	24.0	34.0
Miami silt loam.	5	108.7	5.80	6.8	19.0	—*	53.0	60.0
0.5-gram Samples Treated with $Ca(OH)_2$ Solution and Dried								
Miami silt loam.	10	800	4.83	—*	69.2	100.4	504.0	710.0
Miami loam....	10	800	5.17	—	64.0	89.2	412.0	684.0
Napanee silt loam........	10	800	5.41	—	43.8	57.0	400.0	634.0
Ontonagon clay loam........	10	800	5.17	—	59.2	69.4	386.0	592.0
Saugatuck fine sand.........	10	800	5.13	—	39.0	40.4	240.0	376.0

*Not determined.

In a further test with $Ca(OH)_2$ conducted to determine the effect of varying degrees of base (calcium) saturation on the power of a soil to fix soluble phosphate in difficultly available form, four 0.5-gram samples of each of eight soils were placed in separate flasks. One sample in each case was wetted with distilled water and the other three with equal volumes of lime water of such concentration as to give applications of 6, 10, and 20 tons of $Ca(OH)_2$ per acre, respectively. After standing over night, the samples were dried on a steam plate. The power of soil, thus treated, to change soluble phosphates to a difficultly available form was then determined as before (5). The phosphorus recovered was taken as a measure of that not fixed and the results are given in Table 6.

DISCUSSION OF RESULTS

The results presented in Table 5 show that in 7 of the 10 acid soils ranging from pH 4.83 to pH 6.30 lime significantly increased the availability of soil phosphates, while in two cases it caused only slight increases. The average available phosphorus content of the seven soils when limed was 63.8 pounds per acre and when unlimed 48.9 pounds per acre.

When soluble phosphorus was applied to these soils, the results were similar. In the case of the five soils to which $CaCO_3$ was added, the lime caused an average increase of 9.7 pounds of available phosphorus per acre. The tests with $Ca(OH)_2$, in which the phosphorus and lime applications were excessive, gave much more outstanding results, the average amount of available phosphorus in the soils after the 800-pound application being when limed, 599.2 pounds per acre, and when unlimed, 388.4 pounds, an average increase of 210.8 pounds per acre.

TABLE 6.—*The influence of increasing additions of $Ca(OH)_2$ (base saturation) to eight Michigan soils on the quantity of phosphorus remaining in readily available form after an addition of 800 pounds per acre of phosphorus applied as H_3PO_4.*

Type of soil	pH of unlimed soil	Pounds available phosphorus per acre in samples which were phosphated after the $Ca(OH)_2$ additions indicated			
		No $Ca(OH)_2$	6 tons $Ca(OH)_2$	10 tons $Ca(OH)_2$	20 tons $Ca(OH)_2$
		Acid Soils			
Miami silt loam....	4.83	504	598	710	740
Miami loam.......	5.17	412	572	684	658
Napance silt loam...	5.41	400	526	634	628
Ontonagon clay loam	5.17	386	496	592	592
Saugatuck fine sand.	5.13	240	372	376	452
		Non-acid Soils			
Brookston clay loam.	7.20	668	676	730	—*
Wauseon loamy sand	7.28	820	854	842	—
Wisner silt loam....	8.00	790	800	800	—

*Not determined.

The data given in Table 6 show the effect of degree of base saturation on the power of eight soils to fix phosphorus in a difficultly available form. With the five acid soils, increased applications of $Ca(OH)_2$ resulted in consistent and significant increases in the amounts of phosphorus which remained in the soils in easily available form after the standard 800-pound application. With the three non-acid soils, applications of lime increased only slightly the amounts of phosphorus which remained available, the greatest increase being 62 pounds in the case of the 10-ton application to the Brookston soil, while with the acid soils the average increase for that application was 210.8 pounds.

It is apparent that increased base saturation and consequent decrease in acidity play an important rôle in increasing the availability of soil phosphorus. Ford (2) reported similar results when soluble phosphate was applied to field plats.

When soluble phosphates are applied to a neutral or calcareous soil, there is an immediate reaction with the active calcium or magnesium which is plentiful in such a soil, and the resulting calcium or

magnesium phosphates remain as stable compounds easily available to plants, excepting in some cases when the amount of calcium carbonate becomes excessive (more than 2 or 3%). In the case of soils with a pH appreciably below 6.5, the calcium and magnesium phosphates dissolve sufficiently so that when they come in contact with hydrated iron oxides, a reaction takes place and basic iron phosphates are formed, which Dean (1) and Ford (3) report as being very similar to dufrenite, the phosphorus of which is but slowly available to plants.

SUMMARY

The influence of hydrogen- and calcium-saturated exchange material separated from bentonite, peat, and mineral soils on the availability of rock phosphate to oats, corn, millet, and buckwheat grown in quartz cultures was investigated. The influence of degree of base (calcium) saturation on the availability of native and applied soluble phosphates in 13 Michigan soils was also studied in the laboratory. It is concluded as follows:

1. The addition of hydrogen-saturated exchange material from bentonite and organic and inorganic soils greatly increased the availability of rock phosphate to crops like oats, millet, and corn which otherwise do not feed well on it. This was evidenced by increased yields and a higher phosphorus and a lower calcium content of the plants. Calcium-saturated exchange material from bentonite was not beneficial in this way.
2. Hydrogen-saturated exchange material from bentonite did not nearly so markedly affect the availability of rock phosphate to buckwheat, a crop which takes up large quantities of calcium and normally feeds well on rock phosphate.
3. It is concluded that, in accordance with the law of mass action, hydrogen-saturated exchange material greatly increases the availability of rock phosphate to crops low in calcium, such as oats, corn, and millet, but not, generally, to crops high in calcium, such as buckwheat.
4. Increase in base saturation through the application of lime to seven soils resulted over a period of 1 to 20 days in significant increases in amounts of readily available soil phosphates. In two other soils there were slight increases. With the same soils, lime helped to preserve the availability of added soluble phosphates.
5. Increasing additions of lime to five acid soils consistently lowered the power of these soils to fix added soluble phosphate in a difficultly soluble form.
6. The results support the contention that an increase in base saturation of soils lowers the immediate availability of rock phosphate to crops like corn and oats but, on the other hand, tends to keep native soil phosphates and those added as soluble salts in the form of calcium phosphate rather than the less available basic iron phosphates.

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A METHOD FOR REMOVING AND DETERMINING THE FREE IRON OXIDE IN SOIL COLLOIDS[1]

M. DROSDOFF AND E. TRUOG[2]

FREE ferric oxide, hydrated and unhydrated, is found in all soils and often makes up a considerable portion of the inorganic colloid fraction of soils. This iron oxide is intimately mixed with the other soil colloids and sticks so tenaciously to the surface of the larger mineral particles that when an attempt is made to separate, mechanically, the colloid fraction from the rest of the soil, much of the iron oxide as well as other colloids are left sticking on these surfaces. Frequently the occasion arises in soil investigations when it would be desirable to remove and determine the free iron oxide in soil colloids. Attempts to do this have not been entirely satisfactory. For this purpose, hydrochloric and oxalic acids have usually been used, but since they also dissolve silicate iron as well as other constituents to a marked extent, their use has not met with general favor. Appreciable amounts of ferrous oxide may be present in poorly aerated soils, but since its solution and removal present no special difficulties, its consideration is dispensed with here.

In working on this problem, the writers were using sodium acid oxalate as the solvent, and in an attempt to speed up the solution of the free iron oxide and thus lessen the time of extraction and hence solution of other constituents, the writers were prompted to introduce hydrogen sulfide into the system, thinking its action might aid in the solution. The action of the hydrogen sulfide was far beyond expectation. It seemed to act on the free ferric oxide without the iron oxide having to go into solution. In another test, the acid oxalate was omitted and the iron oxide was quickly changed to the black sulfides.

In looking up the literature regarding this subject, it was found that hydrated ferric oxide has been used for more than 60 years as an absorbent for H_2S in the purification of coal gas. Wright (4)[3] in 1883 reported that $Fe(OH)_3$ suspended in water turned black when H_2S was introduced, the products formed being a mixture of Fe_2S_3, FeS, and S. Allen, *et. al.* (1) showed that the black iron sulfides produced in the reaction were completely soluble in cold dilute HCl. Recently, Pearson and Robinson (3) summarized the literature on the subject and concluded that a mixture of sulfides is formed.

ACTION OF HYDROGEN SULFIDE ON IRON OXIDE

Preliminary tests with H_2S-saturated water suspensions of 100-mesh limonite showed rapid formation of black iron sulfides which dissolved readily in cold 0.05 N HCl. Most of the original iron oxide was

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[2]Research Assistant and Professor of Soils, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 317.

dissolved by this treatment. To determine whether or not the acidity of the H_2S solution (about pH 4) dissolved the iron oxide before it was changed to sulfides, the H_2S solution was neutralized with NH_4OH before being used. This neutralized H_2S solution was even more effective than the acid H_2S solution, which indicated that the sulfides are formed directly as a result of a surface reaction.

In further tests, samples (50 mg each) of finely powdered limonite and hematite were shaken with 200 cc of H_2S-saturated water adjusted to pH 7 with NH_4OH. The iron sulfides formed were dissolved in 0.05 N HCl and the iron in solution determined. Shaking for ½ hour with subsequent HCl treatment dissolved 90% of the limonite but only 8.5% of the hematite. After 1 hour of shaking, all of the limonite dissolved but only 9% of the hematite, indicating that the amount of surface exposed by the crystalline hematite was not sufficient for rapid action of the H_2S.

Samples of crystalline hematite and goethite and ordinary limonite were then prepared in which the particle size was 0.0001 mm and less in diameter. The goethite and hematite were ground in a tool steel ball mill. Suspensions containing 50 mg of these materials in 200 cc of H_2S-saturated water adjusted to pH 7 with NH_4OH were shaken for ½ hour. The iron sulfides formed were dissolved in cold 0.05 N HCl, the solution filtered, and the iron determined in the filtrate. In the case of goethite and limonite all of the material had dissolved, but in the case of the hematite 7% of the sample remained undissolved. Upon analysis, 40% of this residue was found to consist of SiO_2, indicating the presence of an iron silicate, the iron of which did not react readily with the H_2S. These tests show that iron oxide, hydrated and unhydrated, when sufficiently finely divided reacts quickly with H_2S to form sulfides which are readily soluble in 0.05 N HCl.

ACTION OF HYDROGEN SULFIDE ON ROCKS AND MINERALS

In order to find out if the H_2S treatment would have an appreciable effect on ferric iron as found in igneous rocks and especially in silicate form, 0.1-gram samples of biotite and basalt and a 0.2-gram sample of granite, all ground finer than 100-mesh, were shaken for several hours with 300 cc of H_2S-saturated water solution adjusted to pH 7 with NH_4OH. At various intervals, 10-cc portions of the suspensions were removed and treated with 10 cc of 0.05 N HCl and then filtered quickly. After expelling the H_2S and oxidizing with ammonium persulfate, the filtrates were tested for iron colorimetrically with KCNS. Check samples of the mineral powders were treated with water alone instead of the H_2S solution. Samples of these suspensions were treated with HCl, filtered, and tested in exactly the same way as the others. It was found that the H_2S-treated samples gave only a slight test for iron, the same as the check samples, indicating that what little solution of iron took place was due to the direct action of the HCl on the original minerals and that the H_2S treatment does not readily affect iron in the silicate form.

ACTION OF HYDROGEN SULFIDE ON SOIL COLLOIDS AND BENTONITES

A suspension of an Hawaiian lateritic colloid turned black almost immediately when saturated with H_2S and neutralized with NH_4OH. This indicated the presence of a large amount of free iron oxide. The black sulfides formed were easily dissolved in 0.05 N HCl. A suspension of colloid separated from Colby silt loam subsoil and known to contain free iron oxide also turned black quickly when treated with H_2S and neutralized with NH_4OH. On the other hand, a light yellow colloidal suspension separated from Vesper silt loam subsoil was unaffected upon treatment with H_2S, although total analysis showed it to contain several per cent of iron. This iron, since it does not color the colloid yellow or react with H_2S, is not in the free oxide form and may be assumed to exist as a silicate.

To determine whether or not the H_2S treatment affects the base exchange material, 0.3-gram samples of colloid from Colby and Vesper silt loam subsoils and from a yellow bentonite were shaken for 2 hours with 300 cc of neutral H_2S-saturated water solution. Thereafter, 0.1 N HCl was added with stirring until the black sulfides dissolved, when the suspensions were warmed on the steam bath to drive off most of the H_2S and coagulate the colloid. The material was transferred to centrifuge tubes and washed as follows by decantation using the centrifuge: First, twice with 0.05 N HCl to remove all soluble iron; then, twice with 95% C_2H_5OH to remove water which would interfere with the CS_2 treatment[4]; next, three times with a solution consisting of 1 volume of CS_2 and 2 volumes of 95% C_2H_5OH to remove free sulfur; and finally, four to five times with 95% C_2H_5OH to remove the CS_2 that was retained.

After this treatment, the base exchange capacity was determined as follows: The exchangeable hydrogen was displaced by digesting the colloid on the steam bath for several hours with neutral N $NH_4C_2H_3O_2$ solution and washing twice by decantation with the same solution using the centrifuge. Similarly, the colloid was washed five times with neutral N $CaCl_2$ solution to saturate it with calcium, then with 85% C_2H_5OH until free of chlorides, and finally five times with neutral N $NH_4C_2H_3O_2$ solution to replace the exchangeable calcium which was determined in the filtrate. The exchange capacities before and after treatment with H_2S are given in Table 1.

TABLE 1.—*Exchange capacities of soil and bentonite colloids before and after treatment with H_2S.*

Source of colloid	Base exchange capacity, M. E. per 100 grams	
	Untreated	H_2S treated
Colby silt loam subsoil	90	94
Vesper silt loam subsoil	62	60
Yellow bentonite	126	130

[4]In this paper, all percentages of alcohol are given on the volume basis.

The results in Table 1 show that treatment with H_2S solution does not affect the base exchange capacity, and hence it may be assumed that the exchange compound is unaffected. Further evidence of this is the fact that the H_2S extracts contained only traces of alumina and silica, showing that the action on the silicates was negligible.

For determining the length and kind of treatment most efficient in removing the free iron oxide from soil colloids, samples of colloid separated from Superior clay loam subsoil were shaken with various H_2S solutions for different lengths of time, and then acidified with 0.1 N HCl and the amounts of Fe_2O_3 made soluble determined. The results are given in Table 2.

TABLE 2.—*Percentages of iron oxide in Superior clay loam colloid made easily soluble by different H_2S treatments.*

Nature of H_2S solution	Percentages of iron oxide made soluble and extracted	
	½ hr. shaking	1½ hr. shaking
Saturated water solution of H_2S	5.7	6.8
Saturated 0.05 *N* HCl solution of H_2S	5.8	6.9
Saturated water solution of H_2S neutralized with NH_4OH	6.8	6.8
Saturated water solution of H_2S with excess NH_4OH	6.8	6.7

The data for the ½ hour shaking show that saturated H_2S solution neutralized or made alkaline with NH_4OH is more effective than H_2S solution alone, or that acidified with HCl. At the end of 1½ hours the percentages of iron oxide extracted were practically the same in all cases. A neutral solution of H_2S appears to be best both from the standpoint of rapidity of change of Fe_2O_3 to sulfides and least likelihood of attack of other constituents.

PROCEDURE FOR REMOVING AND DETERMINING THE FREE IRON OXIDE IN SOIL COLLOIDS

After separation of colloid from soil.—Separate the soil colloid from the soil by means of any of the common methods and then suspend a sample (0.3 gram is convenient) of the colloid in 250 cc of water and saturate the suspension with H_2S. Neutralize or make slightly alkaline with NH_4OH (requires about 5 cc of N NH_4OH). Shake for ½ hour, acidify with 0.1 N HCl, adding an excess of about 50 cc to dissolve the iron sulfides completely, and then warm on a steam bath to drive off the H_2S and coagulate the colloid. Transfer the suspension to centrifuge tubes and collect the supernatant liquid by decanting after centrifuging. Wash four times with 0.05 N HCl by decantation after centrifuging. Combine the supernatant liquid and washings and determine the iron therein by any standard method.

In case the soil colloid after removal of the free iron oxide is to be used for other purposes, the free sulfur may be washed out as follows, using a centrifuge: Wash twice with 95% C_2H_5OH, then three times

with a CS_2 solution (1 volume of CS_2 to 2 volumes of 95% C_2H_5OH), and finally four to five times with 95% C_2H_5OH. The colloid should now be free of the sulfur that was introduced.

Table 3 gives the amounts of iron oxide removed by the method outlined from some soil and bentonite colloids, together with the total amounts found by analysis of the untreated samples, and also combined or silicate iron obtained by difference. As is to be expected, the amount of free iron oxide is high in the lateritic soil colloid. It is interesting to note that the combined or silicate iron oxide is higher than the free iron oxide in the Wisconsin soil colloids and that the Vesper silt loam and bentonite colloids contain no free iron oxide.

TABLE 3.—*Free iron oxide, total iron oxide, and combined iron oxide in soil and bentonite colloids.*

Source of colloid	Percentages of Fe_2O_3		
	Free oxide by H_2S treatment	Total oxide by total analysis	Combined oxide by difference
Hawaiian lateritic soil......	26.7	35.7	9.0
Colby silt loam subsoil......	3.5	14.7	11.2
Vesper silt loam subsoil.....	—	6.2	6.2
Superior clay loam subsoil .	6.5	15.7	9.2
Yellow bentonite..	—	4.8	4.8
White bentonite	—	6.3	6.3

Without separation of the colloid from the soil.—The occasion may arise in mechanical analysis, specific gravity separations, petrographic work, and phosphate fixation studies when it is desirable to remove the iron oxide directly from the soil. To do this, treat a 5-gram sample of the soil with a 2% solution of Na_2CO_3 on the steam bath for several hours to dissolve colloidal silica and most of the organic matter. Transfer the material to centrifuge tubes, wash twice with 0.05 N HCl by decanting after centrifuging, and then disperse for 1 hour with a dispersion apparatus arranged as suggested by Bouyoucos (2), but having a paddle wheel made of tool steel and a Pyrex glass cup or jar fitted with Pyrex glass rods so as to avoid contamination with nickel and copper. Transfer the suspension, which should have a volume of about 300 cc, to a 500-cc Erlenmeyer flask, saturate with H_2S, make neutral or slightly alkaline with NH_4OH, and proceed from here on as with the separated soil colloid. Soils containing large amounts of free iron oxide may require more than one treatment for complete removal.

SUMMARY

It was found that the free ferric oxide (hydrated and unhydrated) in soil colloids may be easily separated and determined if the suspension of the colloid is first treated for about ½ hour with H_2S. The H_2S quickly changes the free ferric oxide by surface action to iron sulfides which are easily soluble in dilute acid and may thus be extracted and determined. Combined or silicate iron is unaffected in the limited time required as are also other constituents and the base

exchange capacity. It was found that the amount of free ferric oxide in a lateritic soil colloid was high; in colloids from several Wisconsin soils it was less than the combined or silicate iron; and in one soil colloid and two bentonite colloids it was absent, while the combined iron oxide ranged from 4.8 to 6.3%. Free colloidal iron oxide may be removed directly from a soil without previous separation of the colloid as a whole. This is useful in mechanical analysis including specific gravity separations, petrographic work, and phosphate fixation studies.

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NOTES

THE INTRODUCTION OF VARIETIES OF FIELD CROPS FREE OF DETECTABLE MIXTURES OR SEGREGATIONS

MODERN methods of plant breeding require the growing of a tremendous number of field plants in small areas. Strains with different morphological characters are often grown in adjoining plats. These conditions give ample opportunity for the cross fertilization and the mechanical mixing of types to take place at some time during the testing of a strain or variety. Mechanical equipment with which varieties and strains are handled also gives further opportunity for mixing.

A strain that is developed by an experiment station and eventually found worthy of introduction has been exposed to these conditions. No matter how carefully the material has been handled there is always the possibility that a trace of off-type plants will appear in commercial fields grown from increases of such introductions. A plan is now followed by the Farm Crops Department at the Michigan Agricultural Experiment Station that should reduce to a minimum the possibility of introducing varieties having any detectable mixtures or segregations.

Roguing of plats and cleaning of equipment is carefully executed with all material. Once the strains from the breeding plats have been reduced to one or two considered worthy to be placed in over-state trials, a large number of selections is made from each of them. Seed from these is planted in progeny head or plant rows. Each progeny is carefully examined in the field and the laboratory for any indications of mixture or segregation. Seed of plants from rows judged to be pure is grouped by progenies and planted a second year and the examination process is repeated. This prevents the overlooking of any segregations that depend on several factor differences for their expression. Any progeny showing segregation in the field is discarded before blooming time whenever the character appears in time.

After this rigid test, all progenies having external characters judged to be morphologically alike are grouped into one population and the seed used as foundation stock. The method is followed with wheat, oats, barley, and beans.—E. E. DOWN, *Michigan Agricultural Experiment Station, East Lansing, Mich.*

BEAN HYBRIDIZATION

THE hybridization of beans presents problems not encountered in the crossing of other field crops. Nearly all workers who have attempted to make bean crosses have found that artificial pollinations made under field conditions generally are unsuccessful. Field pollinations are successful in Michigan when cool weather prevails during the blooming period, but this condition occurs so seldom that all bean hybridization work is carried on in the greenhouse.

The points considered essential for the successful hybridizing of beans in the greenhouse as followed at the Michigan Agricultural

Experiment Station are briefly outlined, except for certain details of emasculation and pollination that are well known by all plant breeders. These points are as follows:

1. The temperature of the greenhouse at pollinating time is maintained above 68°F and below 75°F, if possible.
2. The relative humidity is kept very high by having all walks and soil under benches well watered.
3. The emasculation is done one to two days before the flowers normally shed their pollen and is followed immediately by pollination.
4. The pollination, made on any particular day, is accomplished by removing a pollen-covered stigma from a flower that has opened during the early morning and rubbing it over the surface of the stigma of an emasculated flower. The stigma is used because this is the easiest way of obtaining a quantity of viable pollen. Unless pollen-bearing flowers are very scarce, only one pollination is made with a stigma.
5. Care is taken to prevent mutilation of the flower parts of the emasculated flowers as this would tend to cause their drying out and decrease the possibility of the pollen functioning.

By strictly observing these few points, artificial pollination in 55 to 65% of the cases results in the formation of a pod containing from two to five, or even six, hybrid beans.—E. E. DOWN. *Michigan Agricultural Experiment Station, East Lansing, Mich.*

AN IMPROVEMENT IN THE HYDROMETER METHOD FOR MAKING MECHANICAL ANALYSES OF SOILS

MOST soils containing appreciable quantities of organic matter produce a froth during the shaking preparatory to taking the hydrometer reading after dispersion of the soil in the special stirring machine. This froth rises to the top of the suspension column and because of its slow disappearance makes a hydrometer reading for total sands at the end of 40 seconds very difficult. The procedure heretofore employed to overcome this difficulty consisted in blowing at the froth. This scheme, however, has not operated successfully, for the froth does not entirely disappear at blowing; and in many cases, the hydrometer reading at the end of 40 seconds cannot be taken accurately.

In experimenting with various means to eliminate this froth difficulty, it was found that the addition of a drop of ether or any of the heavier alcohols, but especially amyl, would cause the froth to disappear almost instantly, leaving a clean surface on the top of the soil suspension, so that a clear and accurate hydrometer reading could easily be taken at the end of 40 seconds. At the same time, the addition of a drop of these heavy alcohols or ether has no other effect upon the soil suspension than that of breaking up the froth.

It is advisable, therefore, to add a drop or two of amyl alcohol or ether to all soils containing organic matter whose combined sand is to be determined by the hydrometer method. The best time to add the amyl alcohol or ether is when the cylinder containing the dispersed

and shaken suspension is placed on the table preparatory to taking the hydrometer reading at the end of 40 seconds. The drop of alcohol or ether is placed on the froth, which disappears instantly, and the hydrometer is then immediately inserted into the suspension column and the reading taken at the end of 40 seconds.—GEORGE J. BOUYOUCOS, *Michigan State College, East Lansing, Mich.*

BOOK REVIEW

AN ANNOTATED BIBLIOGRAPHY OF THE LOW TEMPERATURE RELATION OF PLANTS

By Rodney Beecher Harvey. Minneapolis: Burgess Pub. Co. II + 223 pages; mineographed, fabroid cover. 1935. $4.

THE 3,412 citations are arranged alphabetically by authors and by subjects. Included are references not only to scientific publications, both foreign and American, but also to agricultural periodicals. Since the winter of 1933–34 was one of severe cold in eastern America, it is gratifying to find 1934 references included in the list.

This publication will be found invaluable to the student of winter injury and low temperature effects upon plants in general; while to the practical worker who is called upon to answer questions in this field, the references to observations and practical experience, many of them anonymous, as recorded in agricultural periodicals will be especially useful. (H. B. T.)

AGRONOMIC AFFAIRS

ORGANIZATION OF THE AMERICAN SECTION OF THE INTERNATIONAL SOCIETY OF SOIL SCIENCE

AT a special called meeting held directly following the banquet of the American Society of Agronomy in Washington on the evening of November 22, 1934, an American Section of the International Society of Soil Science was organized. The Committee which had been appointed earlier in the day reported the following brief constitution which was unanimously adopted.

CONSTITUTION
FOR THE AMERICAN SECTION,
INTERNATIONAL SOCIETY OF SOIL SCIENCE

(Adopted November 22, 1934, at Washington, D. C.)

1. The *American Section of the International Society of Soil Science* shall be composed of those members in good standing in the International Society of Soil Science.

2. *Purpose:* The purpose of the Section will be to serve as a medium of expression for the American Members of the International Society, and as an organization through which these members can transact necessary business.

3. *Officers:* The officers shall be a President, Vice-President and a Secretary-Treasurer. They shall be elected at the annual meeting and shall serve for terms of one year, or until their successors are elected and assume office. The officers shall constitute the Executive Committee.

4. *Duties:* The duties of the officers shall be those that usually pertain to the respective offices. The duties of the Executive Committee shall be to determine policies and programs for the Section, and present their findings at the annual meetings for ratification or rejection. Between meetings of the Society, the Executive Committee shall act for the Society in matters of business.

5. *Meetings:* A business meeting shall be held annually, at such time and place as may be designated by the Section; or in case of no decision by the Section, on call of the Executive Committee.

6. *Dues:* Dues of the International Society of Soil Science are set by that body and are payable to the officers designated by that body. Dues in the American Section of the International Society shall be fifty cents per year. Annual dues may be waived or omitted for any year by decision of the Executive Committee if, in their judgment, the treasury has sufficient funds to carry on the functions of the Society without payment of dues.

Immediately following the adoption of the constitution, the following officers were elected: W. P. Kelley, California, *President;* G. W.

Conrey, Ohio, *Vice-President;* and A. G. McCall, Washington, D. C., *Secretary-Treasurer.*

Following the election of officers, S. A. Waksman of New Jersey and M. F. Morgan of Connecticut were selected to constitute a committee on arrangements for those who may be attending the International Congress of Soil Science to be held at Oxford, England, July 30 to August 7, 1935.

Members of the International Society of Soil Science are urged to affiliate with the American Section by sending their application and dues to the Secretary-Treasurer, Doctor A. G. McCall, Bureau of Chemistry and Soils, Washington, D. C.

THIRD INTERNATIONAL CONGRESS OF SOIL SCIENCE

THE Third International Congress of Soil Science will be held in Oxford, on July 30 to August 7, 1935, under the Presidency of Sir John Russell, Director of the Rothamsted Experimental Station, England. The two previous congresses of the series were held in Washington in 1927, and in Leningrad and Moscow in 1930, and were notable for the exceptionally international character of the personnel and the discussions.

The forthcoming Congress will meet as a whole in six plenary sessions at which a general survey of recent advances in every branch of soil science will be made, and it will also work in sections of commissions dealing specifically with (1) soil physics, (2) soil chemistry, (3) soil microbiology, (4) soil fertility, (5) soil classification, and (6) soil technology. Three sub-commissions will discuss problems relating to alkali, forest and peat soils.

A 16-day excursion round Great Britain, leaving Oxford immediately after the Congress and terminating in Cambridge on August 23, has also been arranged for the benefit of members wishing to obtain firsthand knowledge of British agriculture and soils. Every member of the Congress will receive a copy of the official transactions, including the full text of papers read at the plenary sessions and detailed reports of the discussions at the Commission sessions. The cost of the transactions will be included in the Congress fee ($10), payment of which will also entitle members to attend all meetings, receptions, etc., held in connection with the Congress. College accommodation during the Congress can be reserved through the Organizing Committee. Those who are planning to take part in the excursion must deposit a registration fee of $10 before June 30. Intimation of attendance at the Congress should be sent as soon as possible to the Secretary of the Organizing Committee, G. V. Jacks, Imperial Bureau of Soil Science, Harpenden, England, from whom all further information may be obtained, and to the Secretary of the American Section, A. G. McCall, Bureau of Chemistry and Soils, U. S. Department of Agriculture, Washington, D. C.

In order to facilitate matters of transportation to the Congress for the American delegates, a committee was appointed by the American Section of the International Society of Soil Science, consisting of S. A. Waksman, New Jersey Agricultural Experiment Station, and M. J.

Morgan, Connecticut Agricultural Experiment Station. This committee has determined that the approximate cost, for American delegates and those accompanying them, of the Congress and excursion, including tourist transportation from New York and return to New York, will be about $380, with a reduction to members of the International Society of about $20. The committee recommends the following accommodations:

French Liner, Ile de France, leaving New York on July 20 and arriving at Plymouth on July 26, thus allowing three days to be spent in London before the Congress. Return on the *Champlain,* which leaves Southampton on August 24. However, the members have the privilege of returning on other steamers (*Champlain,* Aug. 7[1]; *Normandie,* Aug. 14[2]; *Ile de France,* Aug. 21[2]; *Normandie* Aug. 28[2]; *Lafayette,* Sept. 4[1]; *Ile de France,* Sept. 11[2]), from either Southampton or Havre. The U. S. Revenue Tax of $5.00 must be added to above quotation. It may be noted that railroad transportation from Plymouth to London as well as from London to Southampton will be provided. Members desiring to continue to the Botanical Congress in Amsterdam (September 2 to September 7) may do so without additional transportation expense, railroad tickets being provided from London to Amsterdam, from Amsterdam to Paris, and from Paris to Havre.

The American Shipper of the U. S. Lines leaves New York on July 20 and arrives at Liverpool on July 29. Accommodation tourist class on this steamer will be about $40 less than the above quotation for the round trip. However, no transportation from and to Liverpool will be provided. One may return from London on the *American Merchant* leaving August 30.

Everyone contemplating going to the Congress is urged to write immediately to one of the members of the committee. It is understood that the above quotation will only include the Congress, excursion, and actual transportation and will not include board and lodging and incidental expenses en route to the Congress from Plymouth and after the excursion. It is also understood that the quotation applies only if at least 25 members travel in one group going from New York. The Committee will make arrangements for reservations in line with the above plans.

MEETING OF CORN BELT SECTION OF SOCIETY

THE following program has been arranged for the summer meeting of the Corn Belt Section of the Society to be held at St. Paul, Minn., June 25 to 27:

June 25, Morning, University Farm Auditorium

Joint meeting with Dairy Science Association; American Society of Horticultural Science; Great Plains Section, American Phytopathological Society; American Society of

[1]Slight reduction in above rate.
[2]Slight addition to above rate.

Plant Physiologists; Section O American Association for the Advancement of Science.

Symposium: "Improving the Germ Plasm of Domestic Plants and Animals."

June 25, Afternoon

Field trip to Moscrip's farm, Lake Elmo, to observe studies of pasture management.

June 26, University Farm

Field trip to observe the work of the Divisions of Agronomy & Plant Genetics and Plant Pathology & Botany (in cooperation with American Phytopathological Society and American Society of Plant Physiologists).

June 27, Morning

Field trip to Lake Mille Lacs, visiting on the way the High-lime Peat Experimental Field at Coon Creek and the Low-lime Peat Experimental Field at Page, 12 miles south of lake Mille Lacs.

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SOLUBILITY OF SOIL PHOSPHORUS AS AFFECTED BY MOISTENING AND DRYING BASIC SOILS[1]

T. J. DUNNEWALD[2]

RECENT work with some Wyoming soils indicates that previous treatment of the soil samples affects the results obtained with the modified Denige method for available phosphorus. Some of the older irrigated alfalfa and sugar beet fields develop a difficultly soluble condition of the soil phosphates which affects the crops grown, and, in turn, the livestock which consumes the crops.

Bulk samples of such soils, when air dried and stored for varying lengths of time, exhibited decreases in solubility of the phosphorus in weak acid. Application of superphosphate to such stored soils in greenhouse pots gave large increases of corn. However, watering and cultivation of these soils seemed to increase the solubility of phosphorus to fully as high a point as did fertilizing. Some results of a greenhouse test on such soils, made in 1930, are shown in Table 1.

All the soils shown in Table 1 responded to applications of superphosphate in pot tests. Applications of horse manure, however, gave decreased yields, while watering and cultivation for 10 weeks increased soluble phosphorus about as effectively as did applications of superphosphate. Also on all soils, when watering and cultivation ceased and the soils dried out, the phosphate solubility again decreased. Moisture determinations before and after drying showed that the soils lost from 3 to 8% of moisture, all pots having been kept previously close to 16% moisture.

In the above experiment the samples of soil were removed from the pots by means of a small cork borer tube, dried at 90°C for 1 hour, passed through a 0.5-mm sieve, and weighed out for analysis. The Truog stannous molybdate method was used.[3]

It was believed that the depressed solubility exhibited by the stored soils might be due to heat, light, moisture, carbon dioxide conditions, or to a combination of any of these. Hundred-gram portions of three of the soils were placed in small, clean flower pots and

[1]Contribution from the Agronomy Department, University of Wyoming, Laramie, Wyo. Received for publication January 7, 1935.
[2]Assistant in Soils Investigations.
[3]TRUOG, E. Determination of readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22 : 874. 1930.

treated in various ways before testing for soluble phosphorus. Each pot received treatment once a day and samples of soil were removed after the first, third, and fifth treatments. Table 2 shows the results obtained.

TABLE 1.—*Effect of different treatments on soluble phosphorus in Wyoming soils.*

Treatment	Soluble phosphorus in p.p.m. in soil								
	No. 9	No. 8	No. 7	No. 6	No. 5	No. 4	No. 3	No. 2	No. 1
Sample 2 weeks from field	21	20	9	17	14	48	19	35	11
Group 1, after 10 weeks cultivation and watering in pots	40	44	23	46	40	68	42	75	37
Group 2, superphosphate added, 200 lbs. per acre; cultivated and watered 10 weeks	54	47	16	24	25	54	19	46	25
Pots in group 1 after drying 48 hours	17	8	9	9	10	18	9	23	9
Pots in group 1 after drying 96 hours	16	8	10	10	10	12	9	25	10

TABLE 2.—*Soluble phosphorus in three soils under varied laboratory treatment.*

Treatment	Soluble phosphorus in p.p.m.								
	Soil 1			Soil 2			Soil 3		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
Kept at 15% moisture	47	50	40	16	23	14	9	14	14
Heated 30 min. to 95° C.	46	60	43	17	24	13	10	19	17
Stirred dry	49	64	45	17	20	15	9	17	17
Stirred with 15% water	32	52	38	17	21	16	10	15	14
Moistened, stirred, and dried at 95° C.	35	54	47	17	24	12	9	21	14
Stirred and dried at 95° C.	54	59	46	17	29	12	15	24	15
Untreated	54	60	44	17	24	13	14	21	13

A peculiar tendency is shown in these three soils to approach a maximum solubility in the second sampling or the third day of treatment. Drying, stirring, and moistening produced the greatest variations.

Soils not previously stored did not show these variations. Exposure to saturated carbon dioxide air did not cause variations in solubility to any extent, and nitrogen fertilization seemed to produce such variations when accompanied by cultivation and alternate drying

and moistening. When soluble phosphate was added to some of the soils, it quickly became less soluble at first, but under cultivation, drying, and moistening more phosphorus came into solution.

Fairly large bulk samples of the soils were placed in an autoclave for three quarters of an hour at 15 pounds pressure. They were then dried and stored for three months as previously. The steamed soils still showed variations in solubility for the phosphorus after storage, but they did not do so unless they were also stored for a period.

Table 3 shows the reactions of two soils, one of which was steamed and dried but not stored, while the other had a period of storage in addition to the steam treatment.

TABLE 3.—*Effect of different treatments on the soluble phosphorus in steam-treated soils.*

Trial No.	Date	Soluble phosphorus in p.p.m.							
		Check, not steamed air dry, cultivated	Steamed, cultivated, dry only	Steamed, cultivated, 5% moisture	Steamed, cultivated, 10% moisture	Steamed, cultivated, 20% moisture	Steamed, 0.025 gram K_2PO_4, cultivated at 5% moisture	Steamed, 0.025 gram K_2PO_4, kept at 10% moisture	Steamed, cultivated, 0.025 gram K_2PO_4
Virgin Station Soil, Steamed But Not Stored									
1st.......	May 27	11	13	13	14	14	20	21	65
2nd......	May 29	15	15	16	13	14	83	77	84
3rd......	May 30	17	24	19	18	17	84	85	83
Soil Ph...	May 30	8.3	8.3	8.3	8.6	8.6	8.3	8.5	8.3
Wheatland, 16-year-old Alfalfa Soil, Steamed and Stored 3 Months									
1st.......	May 27	12	12	13	15	14	42	25	16
2nd......	May 29	16	14	14	16	15	90	64	91
3rd......	May 30	35	35	25	18	13	125	58	65
Soil pH...	May 30	8.3	8.1	8.1	8.3	8.3	8.3	8.1	8.1

This experiment indicates that the changes in solubility were probably not due to bacterial activity in these soils. Drying, moistening, and cultivation after a period of storage account for the largest variations. Here is suggested an interesting study concerning the possible effects of moistening and drying and of cultivation upon phosphorus solubility in field soils.

Until it became quite obvious that storage caused reduced solubility of phosphorus in these soils, no single soil had been traced clear through the solubility cycle, *viz.*, from field to storage with low solubility and back to high solubility in the greenhouse or laboratory. For this purpose a profile of virgin Experiment Station farm soil and a

profile of a podsolized soil from the timbered mountains at 8,500 feet elevation were collected. The samples were screened, air dried, and tested for soluble phosphorus at once, then put into storage in large earthenware crocks for 30 days and phosphous solubility again tested. Parts of the samples were placed in open paper bags beside the crocks for comparison. Table 4 shows the reductions in solubility of the phosphorus in the acid and basic soils caused by storage for 30 days.

TABLE 4.—*Effects of storage and subsequent moistening upon the solubility of phosphorus in basic and acid soils.*

Soil horizon	pH	Percentage free $CaCO_3$	Replaceable Ca, M.E. per 100 grams dry soil	Soluble P in field soil, p.p.m.	Soluble phosphorus in p.p.m. after		
					Storage in open sacks	Storage in jars 30 days	Finally wetted and air dried
			Experiment Station Soil				
Virgin bench A_0	6.7	1.5	0.642	70	57	36	57
Virgin bench A_1	6.1	0.74	0.557	46	40	31	41
Virgin bench B_0	7.3	2.50	0.725	18	15	18	24
Virgin bench B_1	8.1	11.50	0.485	17	28	20	28
New alfalfa soil A_1	6.8	1.4	——	111	30	32	112
Old garden soil A_1	7.2	1.64	——	120	21	18	116
			Acid Timbered Mountain Soil				
Mull	5.8	0.15	1.538	51	45	44	60
Duff	5.9	0.14	0.568	70	62	60	64
Gray F.S.L A_0	5.9	0.00	0.309	44	38	30	42
Gray F.S.L A_4	5.9	0.00	0.126	13	13	12	14
Gray loam B_1	5.9	0.00	0.105	12	12	11	10
Coarse loam B_2	5.8	0.00	0.133	10	10	10	12
Pink sandy loam C	5.8	0.00	0.308	14	15	13	20

This experiment indicates that the greatest reductions in solubility occurred in the rich garden and alfalfa soils. The acid organic matter and acid soils show much smaller effects than the bench soils. The high lime subsoil horizons act differently than the lower lime surface horizons. The experiment was repeated with an open beaker of water present with the soils in the jar during storage, but no effect upon the result was noted.

SUMMARY

Certain arid and irrigated soils exhibited a reduction in solubility of their phosphorus when stored air dry in a closed dark space. The reduction was as high as 50 to 80% in some soils and was much lower in acid than in basic soils.

The solubility was restored almost completely by moistening the stored soil with distilled water and allowing to dry overnight.

The horizons containing the organic matter were most affected and the high lime subsoils reacted differently. The phosphorus made soluble by cultivation and moistening of stored soils seemed to be available for plant growth in pots in the greenhouse.

Hydroxyl ions are active in phosphorus replacement and the results cited in this paper may possibly be explained on this basis.[4]

[4]McGEORGE, W. T., and BREAZEALE, J. F. Studies on iron, aluminum, and organic phosphates and phosphate fixation in calcareous soils. Ariz. Agr. Exp. Sta. Tech. Bul. 40. 1932.

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RAVIKOVITCH, S. Adsorption of the phosphoric acid ions by soils. Soil Science, 38 : 219. 1934.

PHOSPHATE AVAILABILITY IN CALCAREOUS SOILS: A FUNCTION OF CARBON DIOXIDE AND pH[1]

W. T. McGeorge, T. F. Buehrer, and J.F. Breazeale[2]

THE rapidly expanding use of phosphate fertilizers in the Southwest, and in many parts of the West in general, is rather convincing evidence of the state of phosphate availability which exists in these soils. Briefly stated, the soil conditions are as follows: (a) The presence of carbonato-apatite as the dominant natural phosphate; (b) an excess of solid-phase calcium carbonate, and (c) varying amounts of free hydroxyl ions. There is no deficiency of potential phosphate reserve, as the presence of similar amounts of carbonato-apatite in non-calcareous soils would be sufficiently available to supply the phosphate needs of crops for many years. The phosphate problem of the Southwest, therefore, largely concerns an environment which depresses the ionization or breaking down of the carbonato-apatite complex. In this environment the presence or absence of carbon dioxide is a dominant factor.

The literature concerning carbon dioxide or carbonic acid in soils is very extensive and clearly portrays its importance in soil processes. This, however, is most fully appreciated by the students of alkaline-calcareous soils. There is scarcely a single undesirable soil property of alkaline soils which does not respond favorably to carbon dioxide. This applies not only to the various changes needed for alkali soil reclamation, but also to plant food availability and its absorption by plant roots. The continued observance of the importance of carbon dioxide to the fertility of southwestern soils has led us to suggest that it is the greatest growth-limiting factor in the cropping of these soil types.

The rôle of carbon dioxide in phosphate availability and its absorption by roots is an outstanding property. It functions in reducing the pH of the soil, or OH ion concentration of the soil solution, which in turn favorably influences phosphate nutrition in three ways, as follows:

1. Ion absorption by plant roots is greatly restricted by the presence of OH ions in the soil solution. Carbon dioxide neutralizes soluble hydroxides and carbonates.
2. The ratio of $\frac{H_2PO_4^-}{HPO_4^{--}}$ is reduced by the presence of OH ions and since plants show a preference for the $H_2PO_4^-$ ion the rôle of carbon dioxide in increasing this ratio is self-evident.
3. The solubility of carbonato-apatite is reduced by the presence of solid-phase calcium carbonate. Carbon dioxide attacks the solid-phase calcium carbonate as well as the calcium carbonate of the

[1]Contribution from the Department of Agricultural Chemistry and Soils, Arizona Agricultural Experiment Station, Tucson, Ariz. Also presented at the annual meeting of the Society held in Washington, D. C., November 23, 1934. Received for publication January 28, 1935.

[2]Head of Department, Physical Chemist, and Research Biochemist, respectively.

carbonato-apatite and thereby increases the solubility of phosphate in the soil solution.

Thus, the solution of the phosphate problem is one of using soluble phosphate fertilizers and getting larger amounts of carbon dioxide into the soil environs.

Phosphate rock or bone are of little or no value in alkaline calcareous soils. On the other hand, response to soluble phosphates has been demonstrated numerous times and the response is immediate if a deficiency exists. This is illustrated by the following experiment. At the University Farm, Tucson, Ariz., an increase of 60% in yield of alfalfa hay was obtained in less than 4 weeks by applying 100 to 200 pounds per acre of ammonium phosphate between cuttings.

In recognizing the favorable influence of carbon dioxide in phosphate nutrition in alkaline calcareous soils, it is self-evident that the efficiency of both phosphate fertilizer and the natural soil phosphate will be greatly enhanced by the presence of free carbon dioxide in the soil environs.

EXPERIMENTAL

Three methods are under study for supplying carbon dioxide to our soils, namely, aeration, organic manures, and chemicals. While aeration is a step in the right direction, largely due to the stimulating effect on root respiration and thereby greater exudation of carbonic acid, it does not of itself exercise a sufficiently effective influence upon the pH of the soil nor the solid-phase calcium carbonate. Organic manures have given excellent response which is in agreement with the results obtained by Pittman (4)[3] in Utah, and they are especially valuable when applied along with phosphate fertilizers. On the other hand, large quantities of organics are not always available in arid regions and this suggests the use of acids in the irrigation water. With unlimited supplies of calcium carbonate in our soils and with a cheap source of acid, this appears to be a feasible way of reducing the pH of the soil solution and at the same time generate a supply of carbon dioxide.

A limited number of experiments have shown this premise to be correct. For example, in a series of experiments in which corn plants were irrigated with water brought to pH 3.0 by sulfuric acid as compared with water of pH 7.0 and 8.5, which cover the pH range of our irrigation waters, the plants in the pots irrigated with the acidified water absorbed considerably more phosphate (2). Since the water at pH 3.0 contains only about 50 p.p.m. sulfuric acid and since this is neutralized immediately on contact with the soil, the effect of the acid is in reality one of carbonic acid. The manner in which the carbonic acid operates is clearly illustrated by the following experiment and discussion of the equilibria involved.

Three pots of acid-washed silica sand were prepared as follows:

No. 1. Control, sand only.

No. 2. Sand plus 5% calcium carbonate and 0.5 gram phosphate rock.

No. 3. Prepared exactly as No. 2.

[3]Figures in parenthesis refer to "Literature Cited," p. 335.

All pots were planted to tomatoes and the first two were irrigated with tap water, while the third pot was irrigated with water saturated with carbon dioxide. The tap water contained 10 p.p.m. nitrate and a trace of phosphate. The comparative growth of the plants at the time of harvest is shown in Fig. 1. The plants were dried and the dry

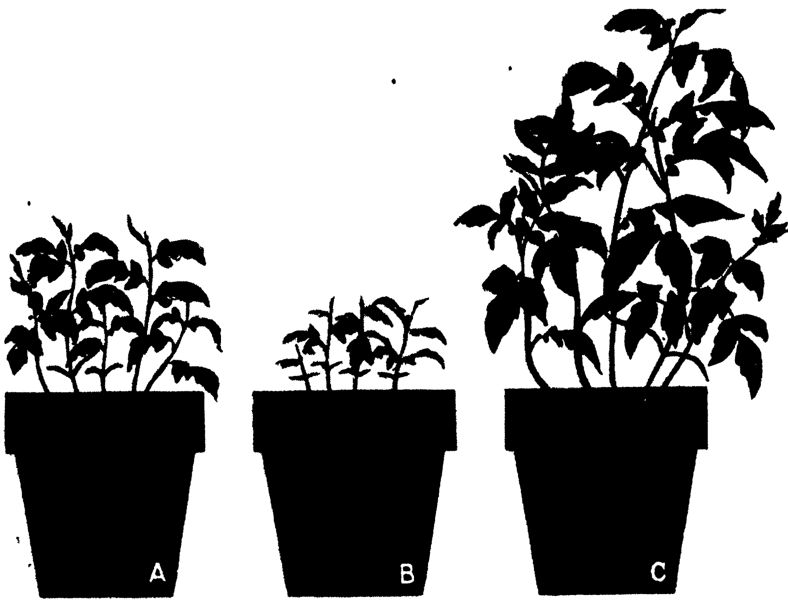

FIG. 1.—(A) Control, silica sand only; (B) phosphate rock and $CaCO_3$ added to sand; (C) same as B. Pots A and B watered with tap water; pot C with water saturated with CO_2.

weight and percentages of nitrogen and phosphate determined. The solubility of the phosphate in the pots was also determined by analyzing the leachate from the pots. These data are given in Table 1.

TABLE 1.—*Dry weight of plants and percentage of N and PO_4 in plants and PO_4 in leachate from pots.*

Pot No.	N, %	PO_4, %	Dry weight of plants, grams	PO_4 in leachate, p.p.m.
1	0.050	0.00302	1.175	0.5
2	0.006	0.00302	0.200	0.0
3	0.315	0.01750	2.625	1.75

These data are self-explanatory and clearly show the value of carbon dioxide in offsetting the undesirable effects of solid-phase calcium carbonate, thereby improving the availability of phosphate of carbonato-apatite. In our alkaline calcareous soils, where aeration is poor, carbon dioxide absent, and little or no soluble calcium salts

are present to furnish the common ion calcium, pH values of 9.0 or even higher may develop from the hydrolysis of calcium carbonate. Thus, carbon dioxide serves the double purpose of reducing the pH to the range where phosphate ion absorption by roots is most active and of breaking down the carbonato-apatite compound. The use of carbon dioxide under field conditions, such as by applying "dry ice" to the irrigation water, is questionable; but with Arizona soils containing 2 to 10% calcium carbonate, it may be economically generated by the use of acids or sulfur. Under field conditions these acid soil amendments have produced increased phosphate absorption by crops on the soils in question.

It should be understood that the soils under discussion are semi-arid soils and practically devoid of organic matter. The above principles would not apply to calcareous soils containing appreciable amounts of organic matter for such soils would possess a microbiological source of carbon dioxide and could not attain the high pH value of alkaline calcareous soils in semi-arid districts.

THEORETICAL

On account of the three-stage ionization of phosphoric acid, all of the various intermediate phosphate ions will be present in solution, their proportions depending upon the pH. By calculation from the three ionization constants it was found that at pH 6.8, which approaches optimum for most plants, HPO_4^{--} and $H_2PO_4^-$ are present in equimolecular proportions (1). The free energy change for the conversion of HPO_4 into $H_2PO_4^-$ is such that these forms are easily converted into one another, being limited only by the solubility of the phosphate salt and the pH of the solution. It is self-evident that pH is an important limiting factor in the absorption of phosphate since plants show a definite preference for the $H_2PO_4^-$ ion.

As will be shown later, in order for natural phosphates to become soluble in alkaline calcareous soils, they must first pass through the dicalcium phosphate form. In view of this, equilibrium measurements must include both the carbonato-apatite and dicalcium phosphate and involve the action of both carbon dioxide and neutral salts which are usually abundant in such soil types.

The effect of neutral salts upon the solubility of these phosphates has been found up to a limiting concentration of about 0.05 N to increase the solubility of dicalcium phosphate, even when common ions are present. Beyond this limit, the common ion effect becomes pronounced. In all cases, however, the effect of pH is far greater in reducing the solubility than is the effect of neutral salts in increasing it. In the presence of both OH^- and CO_3^{--}, the conversion of dicalcium phosphate into carbonato-apatite was found to proceed readily, though not very rapidly.

Since it has been definitely established (3) that the insoluble phosphate which predominates in alkaline calcareous soils is carbonato-apatite, a series of equilibrium experiments were conducted to determine the behavior of these compounds. Dicalcium phosphate and carbonato-apatite were prepared pure and equilibrated, at various pH values, and in the presence of different salts, and the equilibrium

solutions analyzed. Similar experiments were also made with solutions containing different amounts of carbon dioxide. These experiments showed that the conversion of relatively insoluble dicalcium phosphate into the less soluble carbonato-apatite in each case proceded to an equilibrium depending on the pH.

When the equilibrium constants for the action of carbonic acid on these two phosphate compounds were calculated the following results were obtained: (A) $CaHPO_4 + H_2CO_3 = Ca^{++} + HCO_3^- + H_2PO_4^-$, the equilibrium constant for which is 3.07 x 10^{-5}; and (B) $(Ca_3(PO_4)_2)_3.CaCO_3 + H_2CO_3 = 10Ca^{++} + 14\ HCO_3^- + 6H_2PO_4^-$, the equilibrium constant for which is 5.7 x 10^{-40}.

The extremely small value of this latter constant suggested that the reaction as written must be very improbable, though we know that carbon dioxide will make carbonato-apatite go into solution to a limited extent. If the constant for the second reaction is recalculated, using the data obtained for it by experiment but with the mathematical expression for the equilibrium constant the same as that for the first reaction, we obtain the value 2.52 x 10^{-5}. This value checks that of reaction A very closely and leads to the conclusion that dicalcium phosphate controls the equilibrium in alkaline calcareous soils in the manner shown by the following equation: (C) $(Ca_3(PO_4)_2)_3.CaCO_3 + 7H_2CO_3 = 6CaHPO_4 + 4Ca^{++} + 8HCO_3^-$.

From equation C it also follows that if phosphate is to become available, the hydrogen-ion concentration must be sufficient to overcome the common ion effect of Ca^{++} ions and the alkalinity arising from the $CaHPO_4$ and HCO_3^- ions. An exceptionally large concentration of carbonic acid must be present to effect such solubility under alkaline calcareous conditions and even then its solvent action will be limited by the gradually increasing concentration of bicarbonate ions.

It is thus shown that both experimental and theoretical proof can be offered to emphasize the important part which carbon dioxide plays in the availability of phosphate in alkaline calcareous soils. This applies not only to the availability of the natural phosphate but also to the availability and absorption of that added as fertilizer.

SUMMARY

Briefly summarizing, the problems of phosphate availability and phosphate fertilization in alkaline calcareous soils are largely dominated, if not completely governed, by three factors. First, solid-phase calcium carbonate, which is present in abundance, reduces the solubility of the phosphate in carbonato-apatite because of the combined common ion effect of Ca^{++} and CO^{--}. Second, free hydroxyl ions reduce the absorption of phosphate ions by plant roots. Third, free hydroxyl ions modify the normal step ionization of orthophosphate in such a manner that the H_2PO_4 ion, which is preferred if not demanded by plant roots, is largely absent from the system.

Carbonic acid and pH are the key to the availability of phosphate in these soils and our knowledge of the natural form of phosphate present in these soils, together with its properties, suggests that

only water-soluble phosphates be used as fertilizer, and this has been demonstrated experimentally.

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THE INFILTRATION CAPACITY OF SOILS IN RELATION TO THE CONTROL OF SURFACE RUNOFF AND EROSION[1]

G. W. MUSGRAVE[2]

DESPITE the fact that differences in soil types are generally recognized, the pronounced effect of the infiltration capacity of the soil upon the type of erosion control measures which should be recommended has been largely overlooked.[3] Control measures have been recommended that are practically uniform for entire states, whereas the soils within such areas may require entirely different treatment. The absence of quantitative data upon the infiltration capacities of different soils has undoubtedly been the principal reason for the general omission of this factor in the practical application of control measures in the field.

For erosion problems, and in connection also with studies relating, for example, to soil moisture, a method for determining the infiltration capacity of the soil in the field may be most helpful. It has been shown (8)[4] that one of the primary groups of factors affecting the amount of surface runoff from soil in the field is its infiltration capacity. The general pronounced effect of this factor is appreciated only when quantitative data are available. If two soils differ in capacity by as much as ½ inch infiltration per hour over a 4-hour period, the amount of protection provided would differ by 2 surface inches. In many instances this is an amount greater than the effect of the treatment itself.

Any method for the measurement of the infiltration capacity of a soil to be of value in the design of measures for the control of surface runoff obviously must be applicable to the field structure of the soil. Not only that, but it should be applicable to such structure of the soil as permits its *lowest* normal capacity. The results of such measurement giving the *minimum* capacity of the soil may then be safely used in combination with the known capacities of such treatment or treatments for impounding water upon the surface as it may be desired to use.

The purpose of this study has been to develop a method for determining the infiltration capacity of the soil in the field, and to apply the results of such study to the design of treatments for the control of surface runoff and erosion.

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[1]Contribution from Soil Erosion Investigations, U. S. Dept. of Agriculture. Also presented before the annual meeting of the American Soil Survey Association held in Washington, D. C., November 22, 1934. Received for publication February 13, 1935.

[2]Scientist in Soil Erosion and Superintendent, Soil Erosion Stations, Clarinda, Iowa, and Bethany, Mo.

[3]As defined by the section on Hydrology, Amer. Geophys. Union (Trans. Amer. Geophys. Union, Part II, 1934, page 295), infiltration is "The process by which liquid water enters the zone of aeration. It includes the formation and upbuilding of films around soil-grains through wetting by rainfall, melting snow, or temporary sheet-water, and the subsequent progressive downward movement of mobile water through the soil by film-flow after the demand for pellicular water has been satisfied."

[4]Figures in parenthesis refer to "Literature Cited," p. 345.

LITERATURE

Middleton (6), in his study of the properties of soils which influence erosion, has compared the maximum water-holding capacity of seven erosive soils with that of four non-erosive soils. The average for the erosive soils is 42.9% and for the non-erosive 56.2%. Also, he has shown the pore space for these soils. The erosive ones average 32.5% and the non-erosive 45.1%. These comparisons would undoubtedly indicate a higher infiltration capacity for the non-erosive than for the erosive soils. In his study, no comparisons were made between runoff and percolation rates, presumably because of the absence of runoff data. It is probable that a very much greater correlation would be found between runoff and percolation rates than between erosion and percolation rates.

Slater and Byers (9) made a laboratory study of the percolation rates of soil cores which were obtained in the field and forwarded to the laboratory without structural change. The Iredell silt loam, recognized as a highly erosive soil (6), showed a percolation rate of 0.030 inch per hour through open end cores of 14 cm length, while the Davidson clay, recognized as a relatively non-erosive soil, gave a percolation rate of 1.020 inches per hour through open end cores of 20 cm length.

Buehrer (2) has described a method of indicating the structure of a soil based upon the volume-of-flow rate of air through the soil column. He derives an equation for the mechanism of such flow and shows that it is a constant over a wide range of physical conditions. He shows that a comparison between the structure constant and the porosity of various soils is not simply linear as might be expected if all pores were continuous.

Auten (1) has compared the rates of water absorption in old growth forest soils and in adjacent field soils. The forest soils were found to be more porous and had a higher absorption rate than the field soils.

A review of the literature is given by Slater and Byers (9), who note that "very little information is extant concerning the percolation of water through soils of undisturbed structure." It may be added that the above statement is particularly true as applied to the entire soil profile. It is obvious, for example, that percolation rates for a permeable A horizon if lying above an impermeable B horizon may be quite different when determined for the single horizon than when determined for the profile. Ordinarily air must be forced in advance of the moving water. Such movement is very slow through soils of "heavy" structure.

METHODS

Three methods have been used for the determination of the field rate of infiltration of two soil types, namely, the Marshall silt loam, a permeable soil, and the Shelby silt loam, a comparatively impermeable soil. The physical and chemical properties of these soils have been described by Middleton, Slater, and Byers (7).

These methods of measurement were as follows: First, Horton's (3) method in which the available runoff records from known areas were compared with rain intensity curves. The measured runoff was then deducted from the portion of the intensity curve covering the runoff period. The remainder, indicated as the amount of infiltration, was then converted into inches per hour. The second method employed the data from the erosion type lysimeters. In this installation runoff and percolate were measured from soils of normal field structure and of definite surface slope, the columns of soil being 3 feet in length and 3 feet in diameter. The third method was devised in order to provide more rapid progress in obtaining the needed information than was possible with the other methods.

Under normal rainfall the infiltration capacity of the Marshall silt loam is infrequently reached and then only for comparatively short periods. The method used (which provides data even in drouth years) employed the application of water in measured quantities and under uniform head to field soils *in situ*.

FIG. 1.—Apparatus used in making infiltration measurements.

A, seamless tube, 6 inch diameter and of sufficient length to penetrate into the B horizon; B, perforated disk lying on top of soil column; C, calibrated tube for applying water to soil under constant head.

The equipment is shown in Fig. 1. Cylinders usually 6 inches in diameter and of sufficient length to reach the B horizon are forced into the soil by means of jack screws actuating against a convenient movable weight (tractor or loaded truck). These cylinders are of seamless steel tubing sharpened on the lower outside extremity by grinding to a 17° angle. For the Marshall series lengths of 8, 14, and 18 inches have been used, depending upon the depth of the A horizon and its structural condition. For the greater depths of soil and for conditions of very open structure the measurements have been made with 12 or more tubes of 18-inch length. A 1,000-cc dispensing burette with enlarged lower opening and attached rubber tubing and pinch-cock is placed in position above the soil core. A perforated disk is placed on the top of the soil to prevent the development of turbidity when the application of water is made, inasmuch as under such conditions the rate of flow has been shown to be greatly reduced (5).

Ordinarily, from 6 to 12 units are installed for the purpose of making a single determination (Fig. 2). The burettes are filled with water to the upper mark and tightly stoppered. They are then installed so that the lower extremity is approximately 4 to 5 mm above the perforated disk. Thus, a head of water of that height (which appears to be the minimum feasible in practice) is established. During the first half hour readings are made at 5-minute intervals. During the next succeeding hour readings are made at 15-minute intervals. Subsequently, readings are made at 1-hour intervals or greater, depending upon the type of soil and the rate of flow.

RESULTS

Horton's method has been applied to both of the soils in an analysis of runoff covering a 2-year period on the Marshall series and a 3-year period on the Shelby series. Data from the erosion type lysimeters covering a 24-month period for the Marshall series are available. Without going into detail with reference to these results, it may be said that they are in substantial agreement with the results shown for the special method of measurement described herein.

FIG. 2.—Making infiltration measurements in the field.
A battery of 12 units in operation upon Marshall silt loam, sod removed just prior to making measurements; soil moist.

In Fig. 3 the results for a period of 6 hours for the Marshall and Shelby series are shown graphically. These determinations were made in the case of the Shelby series upon a profile located approximately 25 feet distant from the control plats of the Soil Erosion Experiment Station at Bethany, Mo. The determinations were made Sept. 18 after a 1.76 inches rainfall on Sept. 13, a rainfall of 0.37 inch on Sept. 14 to 15, and a 0.16 inch rainfall on Sept. 17. The area was in bluegrass sod and the tubes were inserted after the surface vegetation had been pared off. The profile upon which these determinations were made contains a deeper A horizon than does the profile of the control plats upon which serious erosion has occurred. No less than 4 inches of deep black soil was present in the profile studied. The rates for this impermeable soil are, therefore, believed to be conservatively comparable with those of the permeable Marshall. The site upon

which the Marshall determinations were made lies approximately 100 feet distant from the control plats of the Soil Erosion Station in Page County, Iowa. This profile is practically identical with the profile within the plats themselves. In both instances the locations are upon the same contour as the control plats and have practically identical substructure as that within the plats. On the Marshall site the sod was likewise removed prior to forcing the tubes into the soil.

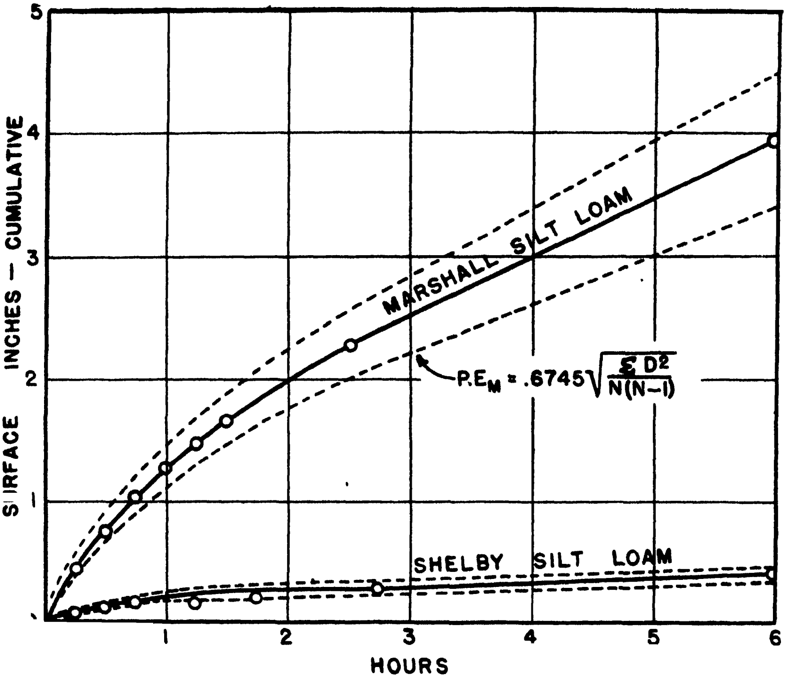

FIG. 3.—Cumulative infiltration for two soils of field structure, both moist and with previous sod surface pared off smoothly.

It is seen from the plotted probable error that the uncontrolled variation is rather large. This seems to be true of most of the reported results for percolation rates. Apparently the soil in its various slight changes in structure is most sensitive to the passage of either air or water. Only by means of ample replication and by most careful procedure is it possible to obtain reliable results. Despite the rather high probable error shown in Fig. 3, it is seen that the difference between the infiltration rates for the two soils is significant.

Plotted curves show that in the first 15 minutes the infiltration rate upon the Marshall silt loam exceeded that upon the Shelby silt loam by 0.38 inch. In the first half hour the Marshall exceeded the Shelby by 0.64 inch. In the first 45 minutes the excess was 0.88 inch. Within a period of 6½ hours the differences exceeded 3.76 inches.

It is of interest to check the above data with the actual measured runoff for Shelby silt loam and Marshall silt loam as determined on

two of the control plats of the Soil Erosion Experiment Station near Bethany, Mo., and two of the control plats of the Soil Erosion Experiment Station near Clarinda, Ia. At both stations there are control plats of like length and cropped continuously to corn. The comparative runoff from these four plats as a percentage of the total rainfall is given in Table 1.

TABLE 1.—*Measured runoff on Shelby and Marshall silt loam in 1933 as percentage of total yearly rainfall, data from control plats of erosion stations.*

Crop	Slope, feet	Shelby	Marshall	Ratio of Shelby: Marshall
Continuous corn......	145.2	27.69	4.10	6.8:1
Continuous corn......	72.6	31.00	4.32	7.2:1

The ratio of runoff of Shelby to Marshall shows that from 6.8 to 7.2 times as much of the respective rainfall ran off from the Shelby as from the Marshall soil.

These ratios of runoff may be compared (Table 2) with the ratios of the infiltration amounts for the same soils as determined by the method of direct measurement described above, and as shown on the graphs of Fig. 3.

TABLE 2.—*Ratios of infiltration amounts for Marshall silt loam to Shelby silt loam for stated periods of time as determined by direct measurement.*

	½ hr.	1 hr.	1½ hrs.	2½ hrs.	6½ hrs.
Ratios............	6.3:1	7.8:1	8.2:1	8.2:1	9.2:1

It is seen from Table 2 that for a half hour period the Marshall silt loam took in 6.3 times as much water as the Shelby. For a 1-hour period the Marshall exceeded the Shelby by 7.8 times. Inasmuch as the majority of rains causing runoff were of comparatively short duration, it is apparent that a ratio of about 7:1 for the shorter periods of time most probably represents the conditions quite accurately. However, the frequency, intensity, and duration of rains to which the two soils were subjected were of course not the same. Thus, under the conditions there is unusually good agreement in the comparison of the two soils by these two diverse criteria, as well as between the three methods which were used for determining the infiltration capacity.

The supreme importance of this factor in the control of surface runoff is at once apparent. Assume that any particular treatment impounds upon the surface of a field 1½ surface inches of water. Taking this amount as a basis of calculation, the protection which is afforded by such a treatment upon the Shelby silt loam is shown in Fig. 4. In this figure the infiltration rate is plotted above the 1½ surface inches which it may be assumed was impounded by a given treatment. Thus, the total degree of protection afforded by the infiltration and the impounding of surface water is somewhat less than 2 surface inches in a 6-hour period.

A highly intensive rain has been plotted upon the same graph for purposes of comparison. The maximum observed rainfall reported over a 42-year period at Des Moines, Iowa, totalled 0.66 inch for a 5-minute period, 1.36 inches for a 15-minute period, and 2.65 inches for a 60-minute period. This curve has been extended arbitrarily to a maximum of 4½ inches in 5½ hours. It is thus seen that the

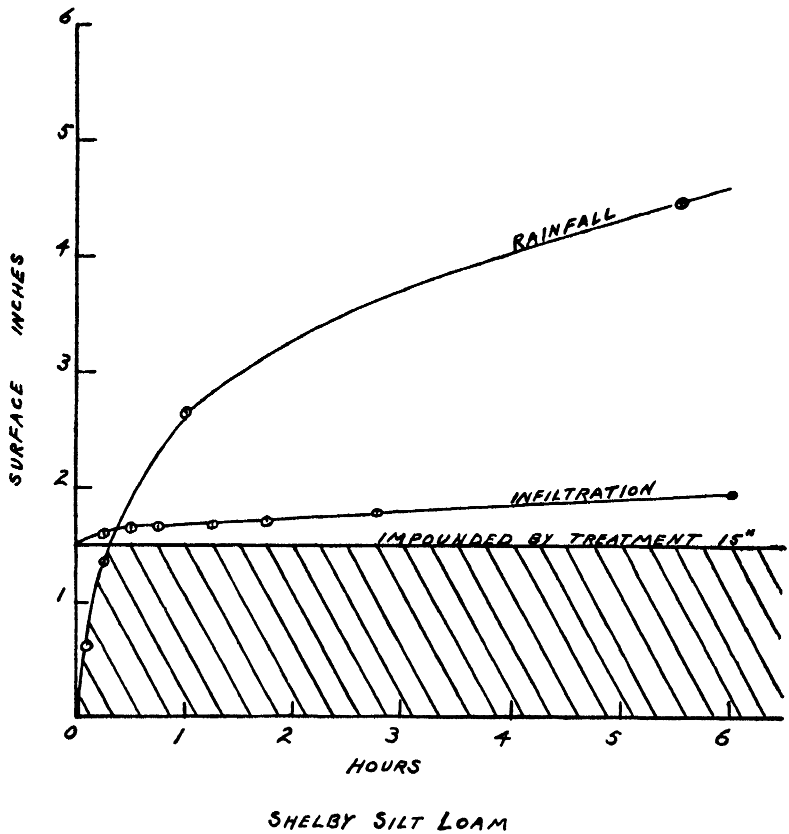

FIG. 4.—Protection provided against runoff on Shelby silt loam for rain of rare intensity and duration and for treatment which impounds 1.5 surface inches of water.

treatment on the Shelby series provides complete protection upon soil of similar structure and moisture conditions to that upon which the infiltration data have been obtained for something less than 24 minutes for a rain of this intensity and duration. At the end of 1 hour nearly 1 inch of rain will have fallen which can neither be impounded upon the soil nor retained within the soil itself. At the end of a 5-hour period there would be an excess of rainfall over protection amounting to 2.45 surface inches under such conditions. This amount would necessarily be lost as surface runoff.

Similar data for the Marshall silt loam are shown graphically in Fig. 5. For a treatment impounding a like amount of water and for a rainfall of like intensity and duration, complete protection is provided throughout the entire period. As a matter of fact the curves would indicate that at the end of a 5½-hour period there would remain a margin of safety approximating a surface inch under these conditions.

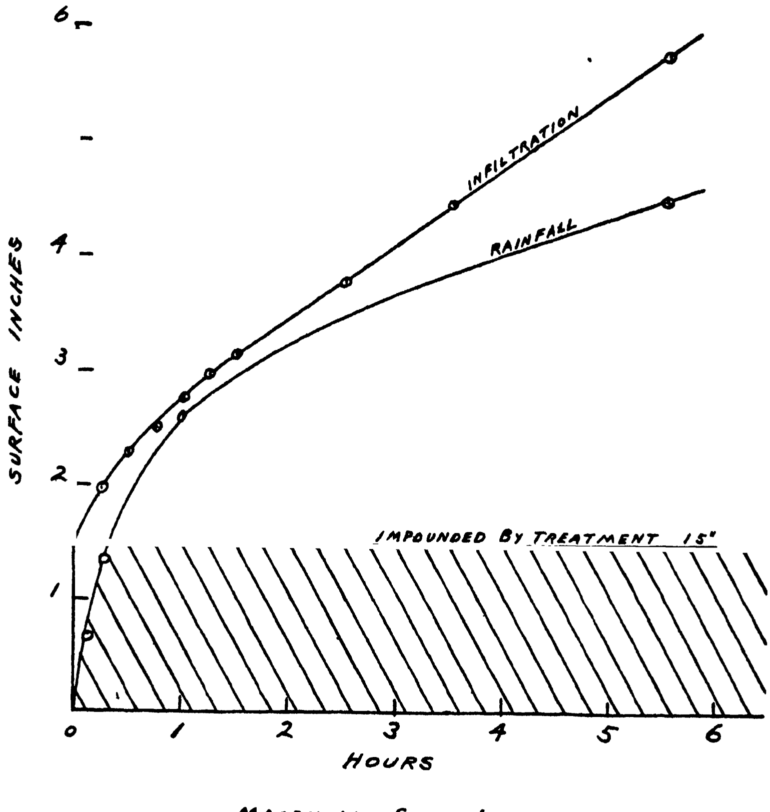

FIG. 5.—Protection provided against runoff on Marshall silt loam for like rain and treatment to that shown in Fig. 4.

DISCUSSION

There are a great many factors which affect the infiltration rates. A separate study is being made of these and will be reported later. However, for the purpose of determining erosion control treatments our interest lies primarily in minimum rates. The results reported herein are for uncultivated moist soil without vegetative cover and are believed to appróximate closely the minimum field rates for each soil.

The amount of water which is impounded by such treatments as terracing, contouring, etc., is approximately determinable. An in-

strument survey giving surficial elevations and plotted on an enlarged scale supplies the essential needs for such conditions as contoured rows and closed end level terraces.

The infiltration capacity of field soils may be determined in several different ways as indicated above. The methods which depend upon normal rainfall are not as suitable for the reason that the application of rain at maximum rates occurs but infrequently. Hence the necessity for a method which will permit the artificial application of water as described herein.

The total of the water impounded, together with the water passing into the soil, permits a fairly precise determination of the volume of precipitation which the treatment will retain upon the field. This total when compared with rainfall curves for the area provides definite information as to the intensities and durations of rain which will cause surface runoff, as well as the amount of such runoff.

Where rainfall data are complete enough to provide frequency curves, a record may be selected which will fit the degree of protection desired. Thus, the rainfall curve of Figs. 4 and 5, with an expectancy of once in 40 years, may be more intensive and of a larger size than economic practice would dictate. Probably a lesser amount, which for example would be exceeded once in 30 years, could be selected as the standard for determining the capacity of the treatment. Even a smaller amount which would be exceeded but once in 20 years might be selected as suitable in the interest of economy. However, in any case, the frequency and probable amount of runoff would be known.

Less precision in the pre-calculation of subsequent erosion is perhaps possible at the present time than is the case for surface runoff. The density of runoff is affected by certain properties of the soil which are probably well indicated by the erosion ratio. In addition, however, the type of vegetation, the length of slope, and many other factors come into play. Data on these points are now being obtained at the various erosion experiment stations.

Under conditions where such factors as amount of water impounded, the infiltration capacity, and the effect of the treatment upon density of runoff are reasonably well determined it seems probable that the degree of protection provided in the field may likewise be predetermined with a fair degree of exactitude. Conversely, where the infiltration rate is known and the effect of the treatment upon density of runoff is likewise known, it seems not impossible that the design of the control treatment for impounding surface water may be determined within reasonable limits of accuracy.

CONCLUSIONS

It is obviously erroneous to attempt to apply like measures for the control of surface runoff and erosion to both permeable and impermeable soils.

The amount of erosion occurring from a field for a rain of given intensity and duration may be approximately predetermined for a given set of conditions if quantitative data are available for (a) amount of water impounded upon the surface of the field by the treatment; (b) the rate of infiltration for the soil and conditions; and

(c) the density of the runoff (pounds of soil per cubic foot of runoff) for the soil and the treatment.

The amount of water impounded by such treatments as terracing, contouring, etc., is approximately determinable. Methods are shown and specific cases given for the measurement of the infiltration capacity of field soils. A considerable body of data already exists which gives the effects of various treatments of many soil types upon the density of runoff.

Before erosion control measures are designed and recommended for general application in the field, their probable effect should first be calculated and the degree of protection which they afford compared with the rainfall records of the area.

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THE APPLICATION OF A MODIFIED PROCEDURE IN NITROGEN TRANSFORMATION STUDIES IN FOREST SOILS[1]

HERBERT A. LUNT[2]

IN nitrification studies with forest soils we had been following the conventional practice of treating the horizon as a unit, i.e., sampling and incubating each horizon separately under optimum conditions of temperature and moisture. Preparation of the samples included mixing and sometimes sieving the mineral soil and cutting the duff material into short lengths (1/8 to 1/4 inch) in a food chopper. While such procedure has its value and should not be discarded, it appears to be rather inappropriate for forest soils in which there may be from two to four distinct horizons in the upper 6 to 8 inches of soil. In the natural state these horizons are in intimate contact with each other and it is a questionable procedure to incubate them separately. Furthermore, there is some doubt as to the advisability of holding the incubating samples at optimum conditions of moisture and temperature when the natural environment may be far from optimum. Therefore, we have tried sampling the whole upper 7 inches as a unit, and incubating the samples out of doors where they are subject to the natural fluctuations in temperature. No separation of the horizons is made until the time of analysis.

DETAILED PROCEDURE

A steel sampling tube, 3 inches in diameter inside and 7 inches long, was constructed out of 3-inch pipe and equipped with an inside collar at the cutting end and a heavy outside collar at the opposite end (Fig. 1). The tube was pushed into the soil to its full length. Usually the upper portion of the forest soil profile is sufficiently loose so that nothing more than standing or treading on the cylinder is necessary to get it into the ground. Generally it is advisable to cut through the duff first with a hunting knife.

The cylinder full of soil and duff was then dug out with a spade and the soil pushed out the top end by means of a plunger into a quart cardboard ice cream container of the same size and open at both ends. The sample was then transferred to a glass jar of the same size and shape. The purpose of the cardboard carton was to enable the operator to have the sample right side up in the glass jar.

Closed with a glass top, the sample was then taken to the laboratory, weighed, and placed out of doors on a shaded bench and allowed to remain there 3 months. By permitting the top to rest loosely on the jar, movement of air was ample and no other means of ventilation was provided. Water was added about every 2 weeks, if necessary, to bring the samples up to weight. Usually from three to five samples were collected in each locality with one or more extra for immediate testing. The time of the original sampling coincided fairly closely with the initiation of biological activity in the spring, usually about May 1 in this climate.

At the end of the incubation period the sample was slipped out into a pan, slit

[1]Contribution from the Department of Soils, Connecticut Agricultural Experiment Station, New Haven, Conn. Also presented at the annual meeting of the Society held in Washington, D. C., November 23, 1934. Received for publication February 11, 1935.

[2]Associate in Forest Soils Research.

open lengthwise, and several portions tested for reaction and for ammonia and nitrate nitrogen by the spot plate method (4).[3] In addition, spot plate tests may be made for soluble calcium, magnesium, phosphorus, potassium, manganese, aluminum, and iron. Finally, as a check on the spot plate tests, a composite of all of the samples from one locality was analyzed quantitatively for ammonia and nitrate nitrogen.

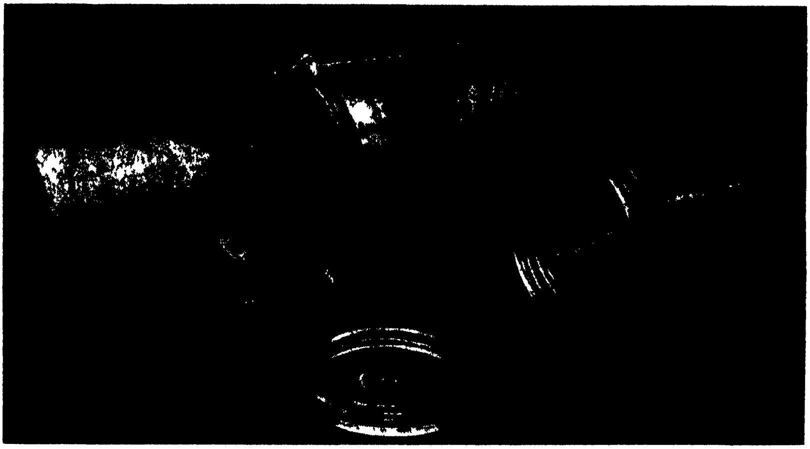

FIG. 1.—Steel sampling tube with cardboard carton attached for receiving the soil sample, plunger used in transferring sample from one container to another, and glass jar used for storage during incubation.

EFFECT OF CONTAINER ON NITRIFICATION

It was originally planned to use cardboard ice cream containers, but it was found that the container interfered with the accumulation of soluble nitrogen to a very serious degree. Jefferies[4] has encountered the same difficulty. Presumably, both the cardboard and its wax coating are responsible, for similar results were obtained when the container was covered with two heavy coats of paraffine regardless of whether the container was made of cardboard or glass. A coating of asphaltum paint was much less harmful than wax, but it did not permit as complete a nitrification as did glass alone. Some of the findings pertinent to this question are shown in Tables 1 and 2.

TABLE 1.—*Effect of container upon nitrification, 3 months' incubation.*

	Treatment applied quart size cardboard ice cream containers				Glass jars
	1 coat wax outside	1 coat wax inside and outside	2 coats wax inside and outside	Asphaltum paint inside and outside	
NO_3 nitrogen, p.p.m.	2.2	21.2	69.2	63.9	77.1
Water added to maintain constant weight, cc	149	316	5	72	12

[3]Figures in parenthesis refer to "Literature Cited," p. 355.
[4]Private communication from C. D. Jefferies.

TABLE 2.—*Effect of container upon nitrification, using soils of varying nitrate content obtained from previous experiment (Table 1).*

Initial nitrate nitrogen in p.p.m.	Net gain or loss nitrate nitrogen in p.p.m.					
	Soil		Soil+tobacco leaves			
	Card-board+ asphaltum paint	Glass	Card-board+ 2 coats of wax	Card-board+ asphaltum paint	Glass	Glass coated inside with wax
2.2......	—	79.3	8.0	5.4	115.1	4.2
21.2......	—	55.1	30.8	12.3	98.4	—17.5
77.1......	—29.4	40.7	—12.1	— 1.6	104.8	—72.0
63.9......	—	—	—11.8*	—	42.3*	—
69.2......	—	—	—	92.4*	104.9*	—

*Quart cardboard ice cream containers and glass fruit jars. All other containers were either ¼ pint cardboard containers or jelly glasses.

STUDIES IN THE SUMMER OF 1934

LOCALITIES SAMPLED

In the season of 1934 samples were taken in the period between April 28 and May 10. Effort was made to select localities representative of a fairly wide range of conditions and some which were of special interest for one reason or another. The locality descriptions follow.

Abbreviation	Description
A — Woodb. R. P. Mull	Woodbridge, red pine (*Pinus resinosa*)[6] plantation; age 19 ± years; good growth; fine crumb mull; Hartford fine sandy loam, gravelly phase.
B — Rain. R. P. Ck.	Rainbow, red pine plantation; block 22, age 36 years; slow growth; Merrimac coarse sand; untreated.
C — Rain. R. P. Limed	Same location. Limed plat.
D — Rain. R. P. Thick duff	Same location. Duff layer is maintained at 3 times the normal thickness. Otherwise the same as B.
E — Rain. W. P. Ck.	Rainbow, white pine (*Pinus strobus*) plantation; block 25; age 36 years; slow growth.
F — Rain. W. P. Limed	Same location. Limed plat.
G — Rain. Gray birch	Rainbow block 18; mostly gray birch (*Betula populifolia*), 2 to 4 inch dia., underplanted with pine.
H — Wind. Mat. W. P.	Windsor, Granby Rd., mature white pine 10 to 15 inches d. b. h. on Merrimac loamy sand. Raw humus.

[6]According to Gray's *Manual*. Ed. 7.

Abbreviation	Description
I — Wind. Young hdws.	Same location as H. Young hardwoods in an opening in the white pine.
J — E. Granby hdws. Podzol	East Granby. Hardwood stand of white oak (*Quercus alba*), red oak (*Quercus rubra*), maple (*Acer sp.*), ash (*Fraxinus sp.*), and cherry (*Prunus sp.*). Merrimac sand. Raw humus over a thin podzol layer.
K — Peoples Forest Mat. W. P.	Peoples Forest. Mature white pine 18 inch d. b. h. on terrace on side of valley. Merrimac sand.
L — N. Cole. Mat. W. P.	North Colebrook. Mature white pine 12 to 18 inches and larger. Level to moderate slope S.
M — Litch. Mat. Hem.-hdws.	Litchfield. Mature hemlock (*Tsuga canadensis*)—hardwoods 12 to 24 inches d. b. h., level, poorly drained muck soil.
N — Litch. Mat. Hem.-hdws.	Litchfield. Hemlock-hardwoods 12 to 24 inches. Higher ground, better drainage, no muck.
O — Litch. Bot.-land hdws. Muck	Litchfield. Bottom-land hardwoods. Poorly drained muck; north side of road. White oak, red maple (*Acer rubrum*), red oak, beech (*Fagus grandifolia*), chestnut (*Castanea dentata*).
P — Litch. Bot.-land hdws.	Litchfield. Hardwoods. South side of road; slightly higher ground, no muck. White oak, red oak.
Q — Beseck hdws. Mull	Beseck, Middlefield. Fast growing hardwoods, excellent mull. Good moisture conditions due to seepage from adjacent hill. Cheshire fine sandy loam to loam.
R — Mt. C. hdws. Mull	Mt. Carmel. Good hardwood stand 6 to 15 inches d. b. h. Red oak, white oak, beech, hickory (*Carya sp.*), red maple, dogwood (*Cornus florida*), occasional small hemlock. Wethersfield fine sandy loam.
S - Bethany. hdws. Raw humus	Bethany. Slow growing hardwoods, mostly scarlet oak (*Quercus coccinea*) and chestnut oak (*Quercus prinus*). Thick raw humus. Gloucester fine sandy loam.
T -- Rain. R. P. Poor	Rainbow, Block 57. Young red pine stand exhibiting poor growth (12th to 14th row away from adjoining locust plat).
U — Rain. Locust	Rainbow, Block 58. Planted to black locust (*Robinia psuedoacacia*) 1903, cut 1923; sprout growth cut 1933. Adjoins block 57.

RESULTS OBTAINED

Total soluble nitrogen.—The quantitative measurements for ammonia and nitrate nitrogen in the mineral soil obtained at the end of the 3-month incubation period are presented graphically in Fig. 2. The samples are arranged in order of decreasing amounts of total soluble nitrogen (sum of ammonia and nitrate nitrogen) and at the same time the amount of each constituent is shown. The outstanding nitrifying samples were from localities A and Q, both excellent mull

types, the locust plat, U, and a limed white pine plat, F. The samples showing the greatest amount of ammonia were the more mature white pine and hemlock-hardwood stands in which there was a considerable accumulation of duff. Vigorous ammonification occurred also in the soil underlying the triple thickness of duff in the 36-year-old stand of red pine (D). It should be noted that the humus types produce just as much soluble nitrogen as do the mulls, but in the former case it occurs as ammonia rather than nitrates.

The data from the limed and unlimed plats at Rainbow show that under white pine, lime not only reduced the formation of ammonia but favored the accumulation of nitrates (compare F with E). Under red pine, on the other hand, lime reduced the ammonia without having had any apparent effect upon nitrates (compare B and C). These results are in agreement with previous tests (2) made on samples from the same plats, and may be explained in part, at least, by the differences in the C-N ratios which are as follows:

	C-N ratios	
	White pine plat	Red pine plat
F	42.0	53.2
A_1	24.7	32.3
A_2	24.0	23.7

Net gain in soluble nitrogen.—The results of spot plate tests made at the initiation and conclusion of the incubation period are presented in Fig. 3 and include data from both the duff and mineral layers. However, the order of arrangement is based upon the decreasing amounts of total soluble nitrogen in the mineral horizon as in Fig. 2. The cross-hatched blocks on the NH_3 nitrogen side indicate a loss in ammonia to the extent shown. There were no losses in nitrate nitrogen. The values shown for the duff samples should be multiplied by 2.

Owing to the nature of the tests, less reliance can be placed upon the absolute values obtained, but on the whole a general agreement can be seen between these results and those shown in Fig. 2. The mineral samples that contained the largest amount of nitrates at the end of the period also made the greatest net gain in nitrates, although the order is not necessarily the same. A like comparison can be made with respect to ammonia.

In the case of the duff samples, except for the locust plat and the limed white pine plat, very little nitrate nitrogen was found. On the other hand, large increases in ammonia occurred in the raw humus and podzol types and under the more mature white pine and hemlock-hardwood stands. It is interesting to note that soil from the mature white pine at Windsor (H) showed a smaller gain in ammonia and a larger gain in nitrate than did the samples taken under young hardwoods (I) growing in an opening in this same white pine stand, although the hardwood soil was less acid (pH 4.7) than the pine soil (pH 4.3).

Effect of locust trees.—The beneficial influence of locust trees reported by McIntyre and Jefferies (3), Chapman (1), and others is revealed here in the superior nitrifying ability of the soil from locality U in comparison with that from an adjoining young red pine stand (T). This is in direct confirmation of the behavior of the trees in the field. The plat next to the locust plat was planted in 1924 with 2-year red pine seedlings spaced 8 x 8 feet. At the present time the first

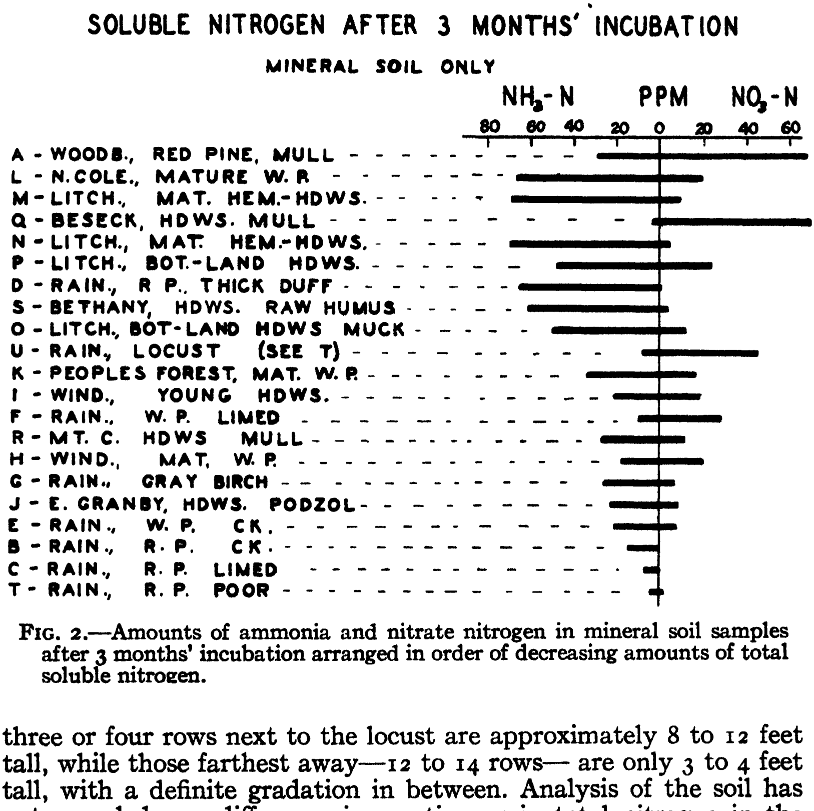

FIG. 2.—Amounts of ammonia and nitrate nitrogen in mineral soil samples after 3 months' incubation arranged in order of decreasing amounts of total soluble nitrogen.

three or four rows next to the locust are approximately 8 to 12 feet tall, while those farthest away—12 to 14 rows— are only 3 to 4 feet tall, with a definite gradation in between. Analysis of the soil has not revealed any difference in reaction or in total nitrogen in the soil under the tall trees as compared with that under the short trees. So far no soil characteristics aside from improved nitrifying ability have been found by laboratory tests which could account for the superior growth of the trees nearest the locust plat.

That tree growth and intensity of nitrification are closely correlated on the plat in question is further substantiated by the results of an incubation study made in the fall of 1933 in which case soil samples were collected from (a) the region of good tree growth, rows 1 and 2 (nearest the locust plat); (b) the region of medium growth, rows 7 to 9; and (c) the region of poor growth, rows 12 to 14. The soils were incubated 3 months with and without the addition of ground dried tobacco leaves (used at the rate of 0.2 gram per 100

grams of soil). The results, shown in Table 3, leave no doubt as to the relative nitrifying capacity of the soil from the several locations. Of particular interest is the accumulation of ammonia in the poor soil when treated with tobacco leaves. For some reason the ammonia was not oxidized into nitrates.

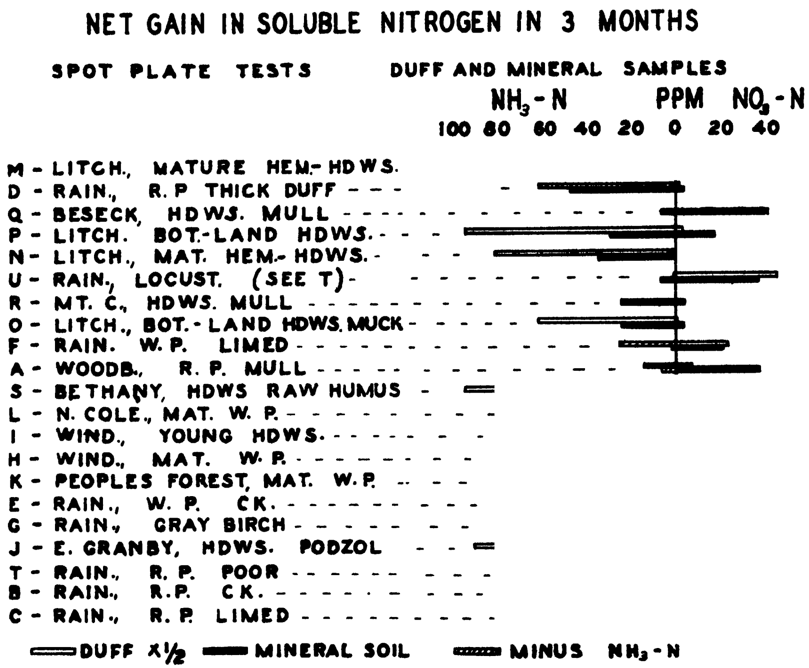

FIG. 3.—Net gain in ammonia and nitrate nitrogen in duff and mineral soil samples after 3 months' incubation arranged in order of decreasing amount of gain in the mineral samples. Values for duff material should be multiplied by 2.

TABLE 3.—*Nitrogen transformation in soil from a red pine plantation, Rainbow, incubation period 3 months.*

Approximate distance from locust plat, feet	Relative growth of red pine trees	NH_3 nitrogen, p.p.m.			NO_3 nitrogen, p.p.m.		
		Initial	Final	Gain or loss	Initial	Final	Gain
			Soil Only				
8–16	Good	0	1.1	1.1	0	20.2	20.2
64	Medium	10	0	—0.10	Trace	1.3	1.3
108	Poor	0	1.4	1.4	0	0	0
			Soil Plus Tobacco Leaves				
8–16	Good	0	0	0	0	69.3	69.3
64	Medium	10	22.2	12.2	0	32.3	32.3
108	Poor	0	42.2	42.2	0	8.1	8.1

Correlations with soil reaction.—Soil reaction was estimated by the spot plate test before and after incubation. Considering the samples as a whole there was practically no correlation with pH nor with change in pH during the incubation period. The mean pH value of all the duff samples was 4.60 before and 4.67 after incubation; and of the mineral soil, 4.57 before and 4.50 after.

However, upon re-grouping the samples upon the basis of gain in either ammonia or nitrates and keeping the duff and mineral samples separate, we find the correlations shown in Table 4. In the duff material there is a correlation, on the one hand, between ammonia nitrogen increase and pH values before incubation and particularly with change in pH. The more acid the initial reaction the greater the amount of ammonia nitrogen formed and the greater the change in pH toward the alkaline side. On the other hand, high nitrate formation is associated with a higher initial pH and a greater change toward a more acid condition than where little or no nitrates are formed.

TABLE 4.—*Correlation of nitrogen transformation with pH.*

Duff Samples					
Av. gain or loss in NH_3 N, p.p.m.	—43	—2.5	70	121	181
Av. pH: Initial	6.27	4.50	4.33	4.07	4.14
Final	5.90	4.20	4.45	4.30	4.55
Change	—0.37	—0.30	+0.12	+0.23	+0.41
Av. gain or loss in NO_3 N, p.p.m.	0	2.8	8.1	68	—
Av. pH: Initial	3.76	4.26	4.60	5.70	—
Final	4.43	4.26	4.59	5.45	—
Change	+0.67	0	—0.01	—0.25	—
Mineral Samples					
Ave. gain or loss in NH_3 N, p.p.m.	—19	—5.8	4.2	25	43
Av. pH: Initial	4.70	4.71	4.56	4.50	4.33
Final	4.65	4.43	4.58	4.55	4.37
Change	—0.05	—0.28	+0.02	+0.05	+0.04

Correlations with other constituents.—Attempts were made to correlate nitrogen transformation with other constituents determined by the spot plate test, namely phosphorus, potassium, calcium, and aluminum. A correlation between ammonia nitrogen and potassium was found, but it is of little consequence because of the interference of ammonia with the potassium test. This test is reliable only when there is little or no ammonia present. In a very general way there is a correlation between nitrogen transformation and calcium content in that a large amount of calcium accompanies a low ammonia and a high nitrate accumulation. No other relationships were discernible.

DISCUSSION

On the whole the results of these incubation studies are in accord with those usually obtained with forest soils of similar nature. The

data obtained serve to confirm the previous findings of the author (2) and others reported by him, rather than to contribute anything particularly new.

The experiment does demonstrate, however, that the procedure followed in this study is satisfactory, and the writer feels it is basically sound both in theory and practice. It is believed that the lower values obtained, in no case exceeding 200 p.p.m., are more in keeping with the amount of soluble nitrogen in the forest than are the much higher values usually obtained, ranging up to 3,000 and more p.p.m., where the samples are incubated under "optimum" conditions. In other words, except in special cases, the investigator should attempt to simulate *natural* conditions as far as practical rather than to use *optimum* conditions.

SUMMARY AND CONCLUSIONS

A modification in the procedure for sampling and incubating soils is proposed for use primarily in forest soil studies. The essential features of this new procedure are (a) sampling about May 1 with a soil cylinder or tube which cuts out a core of the upper 6 or 8 inches with very little disturbance and (b) incubating this sample out of doors subject to the natural temperature changes but not exposed to the direct sunlight.

Glass containers were the most satisfactory. Cardboard, whether paraffined or not, greatly interfered with the accumulation of soluble nitrogen and should not be used.

The results of studies carried on with samples from a rather wide range of forest conditions may be generalized as follows:

1. The mull types found in fast-growing hardwood stands nitrify to a considerable degree with the formation of only a relatively small amount of ammonia.
2. The greatest ammonia accumulation occurred in the thick duff found in mature hemlock-hardwood and mature white pine stands.
3. Lime stimulated nitrification in the soil from a white pine plantation but had little effect in a red pine plantation.
4. Soil from a locust stand nitrified to a marked degree and was in extreme contrast in this respect to a young red pine plantation adjoining. Growth of the red pine trees is directly correlated with the nitrifying capacity of the soil.
5. In general, there is an inverse relation between ammonia accumulation and initial acidity and a direct relation between nitrate accumulation and initial acidity. The change in reaction during the incubation period was toward a lesser acidity where ammonification was greatest and toward a stronger acidity where nitrification was greatest.
6. There was no correlation between nitrogen transformation and the amount of other soil constituents as determined by the spot plate method.
7. The procedure followed has proved satisfactory and the results obtained are believed to be more nearly in keeping with nitrogen changes in the natural forest soil than are those obtained under artificial optimum conditions.

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NITRIFICATION IN THE GRUNDY SILT LOAM AS INFLUENCED BY LIMING[1]

R. H. WALKER AND P. E. BROWN[2]

NUMEROUS experiments have shown that liming acid soils influences their physical, chemical, and bacteriological properties. In studying the effects of liming on the Grundy silt loam in southern Iowa attention has been given to certain chemical and bacteriological effects. The data obtained in the chemical studies have been reported previously (6, 7)[3]. This paper presents the results of one phase of the bacteriological studies made on this soil, namely, the influence of liming on nitrification.

Inasmuch as the nitrifying power of soils has been shown to be closely related to the pH or the buffer capacity, and that it is also rather closely related to or correlated with the crop-producing power, nitrification studies have been made as indicating the influence of liming, not only on a specific physiological group of soil microorganisms, but as suggesting the influence of lime on microbiological activities of soils in general.

EXPERIMENTAL

Grundy silt loam (3) is the most extensively developed upland soil in southern Iowa. It is of loessial origin, dark brown to black in color, and has a rather compact or impervious subsoil. When properly managed this soil is very productive and it may be classed as one of the more fertile soils of Iowa. On most farms, however, the yields of crops are not as large as they should be due mainly to the fact that the soil is strongly acid and in need of lime. This conclusion is supported by the results of previous experiments (3, 4, 5).

Limestone was applied in different amounts and degrees of fineness to one-tenth acre plats of Grundy silt loam in June 1929. Quarry-run limestone was applied at rates of 1, 2, 3, 4, 5, and 6 tons per acre, and limestones of different degrees of fineness employed, namely, 20-mesh, 40-mesh, and 100-mesh, were applied at the rate of 3 tons per acre. A plat treated with hydrated lime in an amount equivalent in CaO content to 3 tons of the limestone was also included in the experiment for comparative purposes. Other plats were left untreated to serve as checks.

The soil of these variously limed plats was sampled from time to time during a period of 5 years, and the nitrifying power was determined. For the determination 30 mgm of N as ammonium sulfate were added to 100 grams (oven-dry basis) of fresh moist soil. The soils were then incubated in covered tumblers at near optimum moisture content and at room temperature for 4 weeks, after which the nitrate content was determined by the phenoldisulfonic acid method.

The hydrogen-ion concentration of the soils was determined potentiometrically by means of the quinhydrone electrode. The results of these determinations have been published elsewhere (6), but some of the data will be included here, inas-

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[2]Research Associate Professor in Soils and Head of Department, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 363.

much as a rather close relationship has been shown between the pH and the nitrifying power of these variously limed soils.

RESULTS

EFFECTS OF DIFFERENT AMOUNTS OF LIMESTONE

The first samples were taken 1 month after the limestone was applied. The pH of the soil and the amounts of nitrate nitrogen produced in the nitrification tests on these samples are shown graphically in Fig. 1. It may be observed that the limestone had exerted an appreciable effect on the hydrogen-ion concentration of the soil during the first month, the increase in pH being a function of the amount of limestone applied. In general, this was also true of the nitrifying power. With one exception each additional ton of limestone applied gave a further increase in the nitrifying power of the soil. The changes in nitrifying power appear to be associated directly with the changes in hydrogen-ion concentration. It is entirely possible, although it is not proved in this work, that the changes in nitrifying power resulted directly from changes in the hydrogen-ion concentration effected by the limestone.

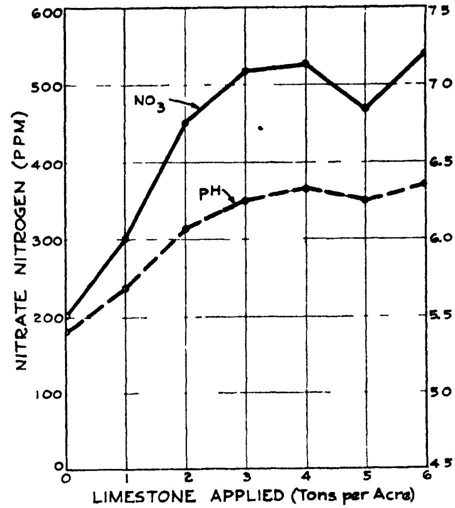

FIG. 1.—Nitrifying power and pH of Grundy silt loam 1 month after liming.

The results of the determinations of nitrifying power at other sampling dates were similar to those obtained at the first sampling. The data obtained in this and in all the subsequent tests are shown in Table 1. From a study of these data it is apparent that the application of limestone to this soil led to an increased nitrifying power, the increase being a function of the amount of limestone applied

It may be observed, however, that there was considerable variation in the nitrifying power of the soil of a particular plat at different times of the year and in different years. Because of this fact a statistical analysis of the data was made by the analysis of variance method suggested by Fisher (1) and described by Snedecor (2). The analysis is shown in Table 2.

This analysis indicates that if the data as a whole are considered, the differences in nitrifying power between the differently treated soils are very highly significant. The differences in nitrifying power between sampling dates are also very highly significant. Inasmuch as this is the case, and since it was purposed to determine as definitely

as possible the effects of different amounts of limestone on the nitrifying power of this soil, the statistical analysis was carried a step further. The significance of the differences between the mean nitrifying power of the variously limed soils was determined. The lowest mean difference between treatments to be significant or highly significant, corresponding to Fisher's 5% and 1% points, respectively, was calculated as follows: M.D. = $\sigma_{M.D.} \times t$.

TABLE 1.—*Nitrate nitrogen in p.p.m. produced in nitrification tests on Grundy silt loam treated with different amounts of quarry-run limestone in the field.*

Date of sampling	No lime	1 ton lime	2 tons lime	3 tons lime	4 tons lime	5 tons lime	6 tons lime
1929							
July 11	203	302	452	518	527	468	541
Aug. 12	136	196	508	559	879	697	774
Sept. 18	70	117	157	197	235	258	267
Oct. 14	71	91	143	173	228	228	237
1930							
Mar. 29	117	216	250	285	266	266	281
June 17	115	146	161	157	167	151	202
Sept. 18	143	182	173	218	197	199	222
Oct. 15	113	145	159	165	193	206	214
1931							
Apr. 6	160	190	206	173	202	205	228
May 20	179	220	232	231	231	237	226
July 16	130	157	175	190	192	198	210
Oct. 19	96	157	184	186	217	239	299
1932							
June 16	173	179	185	193	191	199	202
Oct. 1	56	102	138	173	197	194	206
1933							
May 16	88	118	114	140	182	196	191
Nov. 4	108	134	158	200	228	228	222

TABLE 2.—*Analysis of variance of nitrifying power of Grundy silt loam treated with different amounts of quarry-run limestone.*

Source of variation	d/f	Sum of squares	Mean square
Total	111	19,168	——
Between treatments	6	3,340	556.6**
Between dates	15	11,966	797.7**
Remainder	90	3,862	42.9

**Highly significant.

In this particular case the standard deviation of the mean difference, $\sigma_{M.D.}$, equals 23,156 and t equals 2.042 and 2.750 for the 5% and 1% points, respectively. Thus, the lowest mean difference, M.D., in nitrifying power between two plats to be significant is 47.284, and to be highly significant is 63.679.

The mean nitrifying power of the various soils for the 5-year period was as follows: No lime, 123.1; 1 ton, 166.2; 2 tons, 211.9; 3 tons, 234.3; 4 tons, 271.9; 5 tons, 261.9; and 6 tons, 282.5. Hence, the mean difference in nitrifying power between any two plats treated with limestone in amounts differing by only 1 ton per acre was not quite significant. The mean difference in nitrifying power between the check soil which received no limestone and the soil treated with 2 tons of limestone was highly significant, however. The difference resulting from applications of 2 and 4 tons of limestone was significant, but not quite highly significant. Hence, where limestone was applied up to 4 tons per acre, the increase in nitrifying power induced per ton of limestone was not significant, but the increases induced by 2-ton additions of limestone were significant.

Where larger applications of limestone were made, 2 tons additional of limestone did not give, in all cases, a significant increase in nitrifying power. For example, the increase in nitrifying power of the 5-ton treated soil over the 3-ton treated soil, although appreciable, was not quite large enough to be significant of heterogeneity. Similarly, the increase in nitrifying power of the 6-ton treated soil over the 4-ton treated soil was not significant. The increases in nitrifying power effected by the 5-ton treatment over the 2-ton treatment and by the 6-ton over the 3-ton treatment, a difference of 3 tons of limestone in each case, were highly significant.

These comparisons show that where limestone was applied in amounts less than the lime requirement of the soil or slightly above, the mean increases in nitrifying power induced by 1-ton additional applications of limestone were comparatively large and rather consistent, but they were not quite large enough to be significant. Two-ton increases in amounts of limestone applied, however, induced such large increases in nitrifying power that they were significant or highly significant in each case. Where limestone was applied in amounts beyond the lime requirement of the soil the increase in nitrifying power induced per unit of limestone was reduced somewhat, and larger additional amounts were found necessary to bring about significant increases in nitrifying power.

The above analysis was based upon the results obtained over the entire 5-year period. Although the increases in nitrifying power induced by 1-ton additional amounts of limestone did not prove significant, they were rather large in most cases and undoubtedly they are of real importance. Furthermore, it is very probable that these differences are sufficiently large to have proved significant had there been enough replicate samples taken to warrant a statistical analysis of the data for each date of sampling. There was a rather consistent trend in the changes in nitrifying power, there being an increase in most cases with each additional ton of limestone. Fig. 1 illustrates this point.

The mean nitrifying power for the entire 5-year period has been plotted against the amounts of limestone applied, and the graph is shown in Fig. 2. Thus the data as a whole indicate that there was a rather consistent increase in nitrifying power of this soil induced by additional amounts of limestone applied up to 6 tons per acre, the

largest amount applied. The largest increases induced per ton of limestone occurred with the smaller applications and up to or slightly above the lime requirement of the soil, which was from 3 to 3½ tons per acre. Above this amount the increases in nitrifying power effected per ton of limestone were not so large.

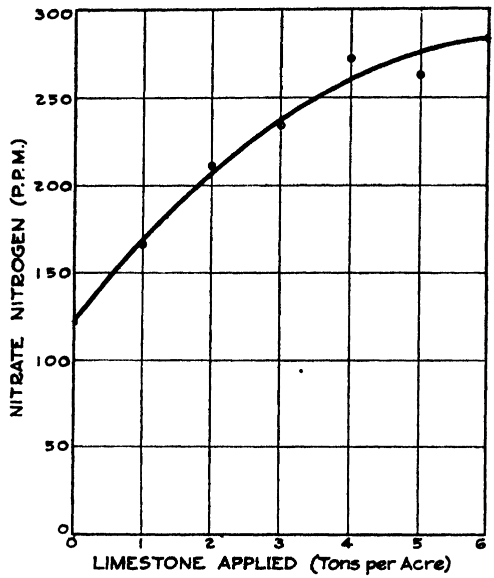

FIG. 2.—The mean nitrifying power of Grundy silt loam treated with different amounts of quarry-run limestone.

EFFECTS OF LIMESTONES OF DIFFERENT DEGREES OF FINENESS AND OF HYDRATED LIME

The plats treated with limestones of different degrees of fineness and with hydrated lime were sampled at the same time as the other plats and the nitrifying power of the soils was determined in the same manner. The results of these tests are shown in Table 3. These data were also analyzed statistically by the variance method and the analysis is shown in Table 4.

The analysis shows that if the results of all the determinations for the entire 5-year period are considered as a whole, the differences in nitrifying power of the differently treated soils are significant. It is also shown that the differences in nitrifying power of the variously treated soils at different samplings are highly significant.

Further statistical analysis was made to determine the significance of the differences between the mean nitrifying power of the variously limed soils. The method was the same as that described above. The analysis revealed the fact that, although the soil treated with 20-mesh limestone showed a higher mean nitrifying power than did the soil treated with quarry-run limestone, the increase was not significant. Similarly, the increases in nitrifying power induced by the 40- and 100-mesh limestones over that brought about by the quarry-run limestone were each too small to be significant, although they were real. The hydrated lime, however, effected a highly significant increase in nitrifying power over that brought about by the quarry-run limestone. Furthermore, the hydrated lime gave a highly significant and a significant increase in nitrifying power over that induced by the 20- and 100-mesh limestones, respectively. The increase in nitrifying power of the hydrated lime treated soil over the soil treated with 40-mesh limestone was apparent, but it was not large enough to be significant.

TABLE 3.—*Nitrate nitrogen in p.p.m. produced in nitrification tests on Grundy silt loam treated with limestones of different degrees of fineness and with hydrated lime.*

Date of sampling	Degree of fineness of limestone				Hydrated lime
	Quarry-run	20-mesh	40-mesh	100-mesh	
1929					
July 11	518	519	528	533	562
Aug. 12	559	558	467	380	801
Sept. 18	197	155	264	249	291
Oct. 14	173	186	242	224	254
1930					
Mar. 29	285	251	275	281	266
June 17	157	192	202	227	196
Sept. 18	218	221	225	225	227
Oct. 15	165	226	232	238	255
1931					
April 6	173	224	223	219	220
May 20	231	217	226	233	234
July 16	190	184	225	226	247
Oct. 19	186	138	255	215	201
1932					
June 16	193	188	195	193	187
Oct. 1	173	129	169	189	202
1933					
May 16	140	182	184	161	178
Nov. 4	200	228	192	165	183

TABLE 4.—*Analysis of variance of nitrifying power of Grundy silt loam treated with limestones of different degrees of fineness and with hydrated lime.*

Source of variation	d/f	Sum of squares	Mean square
Total	79	11,613	——
Between treatments	4	231	57.7*
Between dates	15	10,181	678.0**
Remainder	60	1,201	20.0

*Significant.
**Highly significant.

Although the differences in the mean nitrifying power of certain lime-treated soils were large enough to be significant and others were not, the nitrifying power of the variously treated soils was rather uniform. This fact is illustrated in Fig. 3.

This is what would be expected naturally, inasmuch as the different limestones and hydrated lime were applied in quantities supplying the same amounts of CaO, and the results were obtained in studies conducted over a 5-year period after the lime had been applied. It is logical to assume that the finer limestones would react more quickly with the acids of the soil than would the coarser materials, but over a period of 5 years the coarser limestones would undoubtedly react

sufficiently to increase the pH of the soil to almost the same extent as the finer limestones. This was found to be the case, as previously reported (6). Hence, it is equally logical to assume that for a short period of time after the lime was applied, the nitrifying power of the soil treated with the finer grades of limestone would be higher than that of the soils treated with the coarser limestones. Furthermore, it is reasonable to assume that changes in the nitrifying power would correspond to changes in pH. Hence, comparisons of the mean nitrifying power in studies made over a period of 5 years may be expected to show smaller differences between means for soil treated with limestones of different degrees of fineness applied in equal amounts than for soils treated with quarry-run material but applied in different amounts.

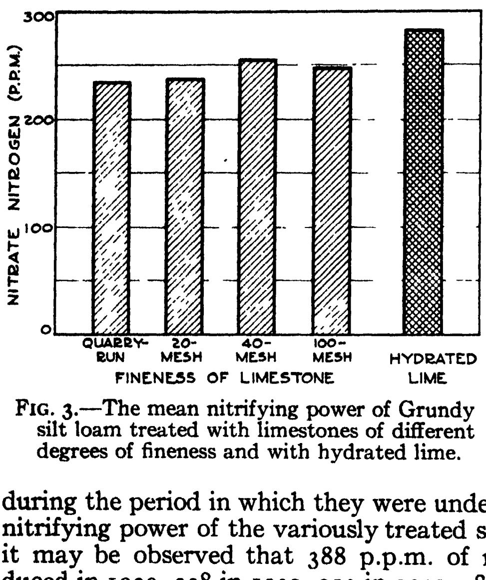

FIG. 3.—The mean nitrifying power of Grundy silt loam treated with limestones of different degrees of fineness and with hydrated lime.

The statistical analysis in Table 4 shows that there was a significant difference in nitrifying power of the variously treated soils at different sampling dates. A study of the mean nitrifying power of the soil of all plats at different dates indicates that there was a rather definite decrease during the period in which they were under observation. If the mean nitrifying power of the variously treated soils per year is considered, it may be observed that 388 p.p.m. of nitrate nitrogen were produced in 1929, 228 in 1930, 213 in 1931, 182 in 1932, and 180 in 1933.

SUMMARY AND CONCLUSIONS

1. Plats of Grundy silt loam were treated with different amounts of quarry-run limestone, with limestones of different degrees of fineness, and with hydrated lime. The soil of these plats was sampled frequently over a period of 5 years and its nitrifying power was determined.

2. The limestones and hydrated lime exerted an appreciable effect on the pH and also the nitrifying power of the soil. The changes in nitrifying power appeared to be associated directly with the changes in hydrogen-ion concentration, these changes being, to a certain extent, a function of the amount of limestone, or of the degree of fineness of the limestone applied.

3. The data were analyzed statistically to determine the significance of the differences in nitrifying power of the variously treated soils. This analysis shows that where limestone was applied in amounts less than the lime requirement of the soil or slightly above, the mean increases in nitrifying power induced by 1-ton additional

applications of limestone were comparatively large and rather consistent, but they were not quite large enough to be significant.

4. Two-ton increases in amounts of limestone applied, induced such large increases in nitrifying power that they were significant or highly significant in each case.

5. Where limestone was applied in amounts beyond the lime requirement of the soil, the increase in nitrifying power induced per unit of limestone was reduced somewhat, and larger additional amounts were found necessary to bring about significant increases in nitrifying power.

6. The 5-year means of the nitrifying power of soils treated with equal amounts of quarry-run, 20-mesh, 40-mesh, and 100-mesh limestones were comparatively uniform, and all except that for the 40-mesh limestone were significantly lower than that for the hydrated lime. The mean difference in nitrifying power between the 40-mesh and hydrated lime treated soils lacked only a very small amount of being significant statistically.

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VARIETAL SURVIVAL OF ALFALFA ON WILT-INFESTED SOIL[1]

L. F. GRABER AND F. R. JONES[2]

THE duration of productivity of established fields of alfalfa on fertile soil in Wisconsin is influenced largely by winter injury, and especially in the southern and western parts of the state, by the bacterial wilt disease caused by *Phytomonas insidiosa*. Winter killing or injury is due, primarily, to climatic conditions and after seeding it may occur during the late fall, winter, or early spring period of any year. Bacterial wilt occasionally destroys a field in a single summer, but usually it develops progressively, reducing the plant population below a profitable level after the third cutting year.

When wilt and winter injury are associated in thinning stands it is difficult to distinguish the degree of loss occasioned by each. As an aid in appraising the losses resulting from these two enemies of the alfalfa plant from the standpoint of survival value under Wisconsin conditions, a field comparison was made of strains of generally known wilt and winter resistance.

PLAN OF EXPERIMENT

The trial was conducted on wilt-infested rolling (Carrington) silt loam soil in Green County, Wis. Alfalfa had been grown in this locality for some 30 years and it is reported that at first stands survived 8 to 10 years. However, since 1925, when bacterial wilt was found thoroughly distributed, stands have not remained productive after the third cutting year.

The soil (3 acres) was properly limed and fertilized with phosphate fertilizer. The area was divided into plats. Two of these were long and parallel strips 4 rods apart, 2 rods wide, and 64 rods long. One of these was sown with winter-hardy and wilt-resistant Ladak alfalfa; the other to winter-hardy and wilt-resistant Imported Turkistan. Between and bordering these two long check plats, eight plats (4 rods x 8 rods, except one 4 rods x 5½ rods) were marked out and sown with wilt-susceptible strains of varying degrees of winter resistance, as follows: Grimm (1 plat), Cossack (1 plat), Canadian variegated (2 plats), Montana common (2 plats), and South Dakota common (2 plats). Each of these plats was separated one from another by a 6-foot alley which was seeded with timothy and clover. The seed used was believed to be fairly representative of these varieties and strains, and all seedings were made on April 14, 1929. Thick and uniform stands of alfalfa were established, and after 1929 the plants were cut under a field schedule of two cuttings annually. No yields were taken, but beginning in April, 1931, when the plants were quite free from winter injury and before symptoms of wilt had appeared, counts of the number of plants on unit areas of $\frac{1}{20,000}$ acre in each plat, were taken at various intervals of time (Table 1). The number of individual counts made at any one time varied with the condition of each plat, consideration being given to any irregularity in stand that had developed.

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WILT INFECTION IN THIRD YEAR

In the late summer of 1931 wilt appeared in all of the plats, though very sparsely in Ladak and Turkistan. During the following winter, plants sustained severe injury for the first time and a marked reduction in stand was recorded by the counts. Nearly all plants, even of Turkistan, showed dead tissue about the base of the crowns, and during a hot dry period in the spring far more plants appeared to die from a drying out of these injured crowns that from wilt, which up to that time did not appear to have caused much loss except in a few small areas. While the winter damage appeared to have been fairly uniform over the entire area, the stands were still in a good productive condition in June, 1932, except in one plat of Montana common. Rapid declines in stand occurred during the summer and fall of 1932 and these appeared to be due largely to the death of plants infected with bacterial wilt. Only Turkistan, Ladak, and Cossack maintained good stands. Grimm and Canadian variegated had a higher survival of plants than the Montana and South Dakota commons, but in the following year they also became very unproductive.

TABLE 1.—*Field losses of alfalfa plants in thickly established stands of several varieties seeded April 14, 1929, on wilt-infested soil.*

Kind	No. plats	Number of live plants on 1/20,000 acre (2,178 sq. ft.)						Condition of stand on July 21, 1934
		Apr. 18, 1931	June 29, 1932	Oct. 31, 1932	Apr. 26, 1933	Oct. 10, 1933	July 21, 1934	
Ladak	Check	58	23	15.2	13.7	9.2	8.8	Good
Imported Turkistan	Check	62	23	15.6	13.1	9.0	9.2	Good
Cossack	1	65	31	14.0	8.4	8.0	4.4	Fair
Grimm	1	60	18	7.7	2.7	1.0	0.6	Poor
Canadian variegated	2	61	21	9.4	3.5	1.5	0.5	Poor
Mont. common	2	54	11	6.8	1.1	0.6	0.6	Poor
S. Dak. common	2	53	18	5.8	2.1	0.4	0.5	Poor

From October 31, 1932, to April 26, 1933, there was another severe loss of plants. The populations of the regional strains of Montana and South Dakota common decreased 84% and 64%, respectively, Grimm 65% Canadian variegated 63%, Cossack 40%, Turkistan 16% and Ladak 10% during this period. While the Ladak and this Turkistan were somewhat more hardy than Grimm and Canadian variegated, the difference was not sufficient to account for the almost complete loss of stand of the two latter varieties. Rather, it appears that the numerous wilt-infected plants of all the susceptible varieties in the fall of 1932 readily succumbed to the winter damage of 1932–33, while Ladak and Turkistan having relatively low infections were able to survive with but a small loss.

While Cossack alfalfa maintained a fair stand even in the fifth year (1934) of the trial, the plant population was less than half that of the Ladak and Turkistan immediately contiguous to it, and many of the plants were dwarfed by disease. Furthermore, disease determinations made from representative samples of these varieties showed that 60% of the Cossack population was infected in contrast with but 20% of the Ladak and Turkistan plants. That the superiority in survival in Cossack in comparison with Grimm and other wilt-susceptible strains in this instance is due to a degree of wilt resistance generally present in the variety appears unlikely from the result of artificial tests. The most extensive of these tests was made at Madison, Wis., in 1934, when 2,000 plants from 17 seed lots of Cossack of known origin were compared. Little difference was found between these lots and on the whole they were not decisively superior to Grimm. Yet, in a previous field trial of 6 years duration on the University Farm, Madison, Wis., another strain of Cossack alfalfa showed a moderately superior survival in comparison with Grimm and Canadian variegated. The reason for this field superiority with the two lots of Cossack alfalfa appears to lie in some character or combination of characters which can only be determined by further experiment. In the possession of qualities which make possible long survival of alfalfa, Ladak and Turkistan proved outstanding in the field test made on wilt-infested soil in Green County, Wis.

SUMMARY

To ascertain the influence of bacterial wilt disease caused by *Phytomonas insidiosa* in shortening the life of stands of alfalfa in southern Wisconsin, a field comparison was made of winter-hardy and wilt-resistant Ladak and Turkistan alfalfa with winter-hardy but wilt-susceptible Grimm, Canadian variegated, and Cossack alfalfa and with the regional strains of susceptible and moderately hardy Montana and South Dakota common alfalfa. All these strains were grown on wilt-infested soil. The field was cut twice annually for five consecutive years and the survival was ascertained by population counts. Wilt appeared in the summer and fall of the third year and all the susceptible varieties, except Cossack, were rapidly and almost completely eliminated by the disease and winter injury at the end of the third and fourth cutting years. Cossack, while severely diseased, proved intermediate in survival between the remainder of the susceptible varieties and the wilt-resistant sorts, but only the resistant Ladak and Imported Turkistan maintained good stands at the end of the fifth year. Wilt infection appeared to reduce the winter survival of such normally hardy and susceptible varieties as Grimm, Canadian variegated, and Cossack so that they appeared superficially like non-hardy sorts after infection.

THE PLACE OF LEGUMES IN PASTURE PRODUCTION[1]

E. N. FERGUS[2]

SOME years ago Campbell[3] presented data which suggest that in eastern United States nature largely uses legumes for building up the nitrogen supply of newly exposed soils, and that as the available nitrogen supply becomes less of a limiting factor in the support of the plant population on a soil, the legumes become relatively much less prominent in the vegetation. It seems reasonable to infer, therefore, that legumes should naturally be present in the pasture flora in eastern United States where the permanent pasture is in reality a preclimax plant community, and further that if they are present their effect, because of their nitrogen-fixing quality, tends to cause the pasture flora to change to an ecologically more advanced plant community.

However, such a change in flora destroys the desirable pasture community, consequently man must neutralize these forces by various practices available to him and thus hold the community more or less constant. Among these practices are fertilizing, liming, mowing, grubbing, and, of course, pasturing itself which probably is effective largely because of the indirect effects of the removal of fixed nitrogen.

If the combined dynamics of these practices balance the dynamics of progressive plant community succession, the flora will remain pracically constant; if stronger, they will force a regressive succession; if weaker, the succession will move slowly toward the climax plant community. Perhaps the contrary forces are never balanced and man must continually vary the intensity of modifiable environmental factors to accomplish this purpose. This is pasture management, the critical element in pasture production.

While we do not wish to imply that there are not other important factors in pasture production, we consider that, economically, the nitrogen supply is by far the most important. It may be, and probably usually is, impossible to grow good grass or legumes without the addition of lime, phosphorus, or potassium or all of them, but it is a comparatively simple matter to supply these deficiencies, and usually the expense is not great. But with mineral deficiencies corrected, the most difficult problem remains, *viz.*, that of supplying, utilizing, and conserving nitrogen.

There are two methods for supplying nitrogen, namely, by applying commercial carriers of the element and by providing for its fixation by legumes and micro-organisms. The value of the former method has not been proved sufficiently, largely because it has not been studied as a consistent practice in the management of permanent pastures. However, there is considerable evidence that its use is

[1]Contribution from the Department of Agronomy, Kentucky Agricultural Experiment Station, Lexington, Ky. Also presented at the annual meeting of the Society held in Washington, D. C., November 23, 1934. Published by permission of the Director. Received for publication February 18, 1935.

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[3]CAMPBELL, ELMER. Wild legumes and soil fertility. Ecol., 8 : 480–483. 1927.

followed by the gradual disappearance of the legumes from the flora, especially if applications of the nitrogen carrier are large. This method of supplying nitrogen needs much study which takes into consideration all factors concerned with the permanency of desirable pasture floras and their economic utilization. The other method of supplying the nitrogen, namely, by natural fixation, likewise has not been sufficiently studied, but it has one important argument in its favor; it is nature's way of doing it. That means that the plant community, which is a natural community, is receiving its nitrogen in response to natural requirements rather than in response to man's desires, which, though admirable, may sometimes lead to practices that destroy rather than build.

Nature seems to have given an example of a satisfactory solution of the nitrogen problem in the ecology and productivity of pastures of long standing in the central bluegrass region of Kentucky where, because conditions are suitable for legumes, they not only supply sufficient nitrogen for productive pastures, but also constitute a highly valuable component of the pasture flora.

That legumes in a pasture provide nitrogen for the non-legume portion of the flora has been rather generally assumed, largely because of the known value of legumes in a rotation. However, some students have observed the effects of legumes on pasture production and consistently have sown legumes in pastures with the idea of improving them. Probably Prof. I. P. Roberts of Cornell University, who established the practice about 1883 on a pasture that bore his name, was first to do this.[4] It is significant that 35 years later he puts the maintenance of legumes in that pasture in the first position in enumerating four factors responsible for its high productivity.

As we have previously stated, nature has long been answering the question of the place of legumes in pasture production and improvement by her procedure in the bluegrass region of Kentucky. The soils are highly fertile, so fertile, in fact, that although cropped for over a hundred years they are still more productive even without the use of fertilizer or manure than are other soils of the state with the most effective soil treatments. Some conception of this productivity may be had from data in Table 1, giving the average corn yields for a 10-year period (1920–29) of the untreated plat on the Lexington soil field and of the highest yielding plat of each field representative of other large soil areas of the state.

Not only has the plat on the Lexington soil field received no manure or fertilizer, but it has had everything except the second clover crop removed. Yet, after 19 years of such farming, preceded by 11 years of general cropping after breaking out of an old sod, this plat still yields as well or better than other soils of the state which have received liberal liming, fertilizing and manuring.

The pastures of the bluegrass region, which, of course, do not constitute the natural climax vegetation of the area, consist almost wholly of Kentucky bluegrass and white clover. These plants are usually found together. One may be dominant one year and the other

[4]ROBERTS, I. P. The Roberts pasture. Cornell Univ. Agr. Exp. Sta. Bul. 280. 1910.

another year. If a pasture is closely grazed continuously, or even frequently, white clover is almost always present and usually widely distributed. If a pasture is always undergrazed, white clover is not present in appreciable amount except at wide intervals, when it may become quite prominent.

TABLE 1.—*Comparative analytical and yield data from certain plats of the soil experiment fields of Kentucky representative of major soil areas.*

Soil field	Plat treatment*	Corn yield in bu., 1920–29	Elements in 2,000,000 lbs. surface soil, lbs.			pH
			P	K	N	
Lexington	None	57.8	10,000	28,000	4,500	5.4
Mayfield	MLPK	58.0	960	29,700	1,920	4.9
Campbellsville	MLPKN	54.6	1,100	13,000	2,375	5.5
Berea	MLPK	51.5	800	19,000	2,200	4.5
Greenville	MLRPK	49.2	660	24,600	1,780	5.5
Fariston	LPK	44.4	820	24,400	2,300	4.5

*None = No lime, manure or fertilizer and all crop materials except second-crop clover removed; L = Ground limestone; P = Superphosphate; RP = Rock phosphate; K = Muriate of potash; N = Nitrate of soda; M = Barn manure throughout the period, except that at Campbellsville it was used 4 years out of 10, and at Greenville crop residues were used 5 years in lieu of manure. For a more detailed report of the treatment and yields of these fields, see Ky. Agr. Exp. Sta. Buls. 322 and 331.

It seems reasonable to believe that these relations between white clover and bluegrass are largely correlated with the available nitrogen balance in the soil. In the frequently or continuously closely grazed pasture, it appears that the competing grass is removed so rapidly that it is unable to occupy a dominant position over white clover. By this process, also, available nitrogen is rapidly removed from the soil, making conditions less favorable for grass and favoring the dominance of white clover. In continuously undergrazed pastures, however, the available nitrogen supply appears to be removed so slowly that nitrification alone is sufficient to maintain for a few to several years bluegrass in the dominant position. Continually without white clover, however, the available nitrogen content becomes gradually lower, even though the total nitrogen content actually remains constant or even increases. The bluegrass concurrently becomes thinner and less vigorous and soon white clover becomes prominent. This is followed by bluegrass in the dominant position again.

The place that legumes have in the maintenance of bluegrass sod and productivity is shown by some experiments on the Experiment Station farm at Lexington in which all legumes were kept out of bluegrass sods in comparison with other sods in which legumes were maintained at least part of the time.

The first measurement of this effect was obtained from an experiment conducted by Karraker[5] in connection with soil nitrogen studies. In the fall of 1923, Kentucky bluegrass was sown in four plats on the Station farm at Lexington. White clover was also sown on two of the plats. All legumes were kept off the other two plats. In the two plats

[5]KARRAKER, P. E. Note on the increased growth of bluegrass from associated growth of sweet clover. Jour. Amer. Soc. Agron., 17 : 813–14. 1925.

seeded to bluegrass and white clover, sweet clover volunteered abundantly in 1924 and was permitted to make large growth, but was removed in 1925, just before seed matured. While the clipped material usually was left on the plat without weighing, it was harvested once in 1926 and twice in 1928. The total harvest from the three cuttings yielded at the rate of 2,600 pounds of dry matter per acre on the grass-alone plat and 6,100 pounds on the grass-legume plat. Practically all the material was bluegrass. The herbage from the legume-free plat averaged 1.56% of total nitrogen and that from the grass-legume plat 2.17%, an increase of nearly 40%. Perhaps it may be of interest that during the 8 years of this experiment, there was a gain in total nitrogen of 132 pounds per acre for the legume-free plats and 684 pounds for the grass-legume combination. The total nitrogen in the surface 18 inches of soil was not increased appreciably under the legume-free herbage, whereas it was increased 400 pounds under the grass-legume combination. At the end of 10 years the sod on the legume-free plat was light and weedy, while that on the bluegrass-clover plats was heavy and free of weeds.

A series of plats was established in 1927 for the express purpose of ascertaining not only the effect of a legume on bluegrass with which it grows from time to time, but also the relative value of different legumes for association with bluegrass. The legumes were, of course, included in the initial sowing on their respective plats. Since then, however, the legume content of the grass-legume plats has not been comparable, primarily because of differences in life history; consequently, it will be many years before any reliable statement can be made regarding the relative merit of any particular legume for improving bluegrass pastures. But the total dry matter production from the alfalfa, sweet clover, red clover, alsike clover, annual lespedezas, and white clover plats in contrast with that from the no legume-bluegrass plat shows the decided value of legumes in pasture production. The no-legume grass plats from 1929 to 1934, exclusive of the last cutting of 1934, have yielded at the average annual rate of 1,670 pounds of dry matter per acre as hay, and the legume-grass plats at 3,590 pounds, an increase of approximately 115%.

These yields are of all the herbage on the plats and consequently indicate little of the legume effect on the bluegrass alone. While it will be impossible to draw reliable conclusions relative to this effect for many years, the yields from certain plats which were free of legumes in some years are significant. For example, the red clover plat was free of that legume in 1931 and 1932. In those years it produced an average annual yield of 2,774 pounds of dry matter as hay, while the legume-free plat beside it produced 1,867 pounds, a difference of 49% in favor of the red clover plat. Again, the first cutting of hay from the legume-free plat in 1934 yielded at the rate of 259 pounds of dry matter to the acre, while the white clover-bluegrass plat yielded 432 pounds, or an increase of 66%, from the residual effect of white clover.

These yields present a very imperfect picture of the situation, however, because all the material from the legume-grass plat was bluegrass, while a large amount of that from the legume-free plat was

weeds. Moreover, legumes not only increase the yield of pasturage and improve bluegrass sod, but they increase the protein content of the herbage of the grass-legume mixtures in comparison with that of the herbage from the grass-alone plats, as illustrated by a representative analysis. The clipping from the bluegrass-white clover plat on September 22, 1933, which consisted of both plants, contained 19.75% protein, while that from the contiguous legume-free plat contained 14.95% of protein, or an increase of 32% in favor of the herbage containing white clover.

The residual effect of the legume also increases the crude protein content of bluegrass. This may be illustrated by a representative analysis. As has been indicated, the white clover-bluegrass plat contained a vigorous stand of white clover in 1933. It disappeared in June 1934; yet the August 22, 1934, clipping from that plat contained 17.95% protein, whereas the clipping of the same date made from the contiguous legume-free plat contained 13.25% protein, or a difference of 35% in favor of the grass which had a legume with it previously.

Legumes appear to affect associated grass in another particular that may be fully as important in the improvement of pastures for high-producing and fast-growing livestock, namely, in increasing the mineral content of the grass. This statement is based on one chemical analysis of bluegrass growing in association with white clover and one analysis of bluegrass growing just outside the boundary of the white clover-bluegrass areas. These samples were taken at the same time from a bluegrass sod of long standing in which there were areas with bluegrass and white clover growing in association and areas of bluegrass in which no white clover could be found. The herbage was 3½ to 4 inches tall when harvested. The analyses are shown in Table 2.

TABLE 2.—*Chemical composition of white clover and Kentucky bluegrass growing in association and of bluegrass growing alone.**

Association	Total protein %	CaO %	P_2O_5 %	SiO_2 %	K_2O %
White clover growing with bluegrass	29.55	2.19	0.98	0.70	4.85
Bluegrass growing with white clover	22.03	0.80	1.00	1.62	3.52
Bluegrass growing alone	16.52	0.68	0.85	2.50	2.96

*Most analyses given in this paper were made by Howell D. Spears, chemist of Feed Control Department, Kentucky Agricultural Experiment Station, as part of a cooperative project between him and the author.

The analyses in Table 2 indicate not only that bluegrass growing in association with white clover contains larger amounts of certain elements necessary in livestock nutrition than does bluegrass growing alone, but also that a white clover-bluegrass association produces forage much richer in those elements than even the bluegrass growing in association with the white clover.

It would be of interest and of value to know how long the bluegrass alone mentioned in Table 2 had been without white clover, because that would give even more information on the immediate effect of the clover. However, the area from which the samples were chosen has

usually had white clover in spots; and since the grass itself was vigorous, it is certain that the grass had the benefit of the legume association within the last few years. It would also be of interest to know what the residual effect of legumes is on increasing the mineral content of bluegrass, but samples taken for this purpose have not yet been analyzed.

Perhaps the most striking effect of a legume on bluegrass is that which is visible to the eye. A statement has previously been made that sods in which a legume is frequently present are practically free of weeds, while that sod which is kept free of legumes becomes thin and weedy. This is only part of the observable difference, however. The differences in number of tillers, recovery after clipping, and color are equally striking. The rate of deterioration of bluegrass sod when legumes are kept out is rather rapid. Under such conditions the grass becomes thin and lighter green, and in from 4 to 8 years becomes weedy.

Summarizing, it may be said that legumes improve pastures by (1) directly and indirectly increasing the total dry matter production, (2) by improving the vigor of the grass sods and preventing weed growth, and (3) by increasing the protein and mineral content of the pasture herbage.

Before concluding, perhaps it should be frankly acknowledged that this paper is not the presentation of a body of data on the place of legumes in pasture production. It is rather an attempt to explain our philosophy of the initial pasture production program—a philosophy based on the foundation of observed differences in the production, management, and ecology of the pastures of the bluegrass region of Kentucky in contrast with those of the rest of the state. In doing this, bits of data from some studies at the Kentucky Agricultural Experiment Station have been presented—studies conducted to obtain a better understanding of the pastures of central Kentucky for the two-fold purpose of learning how to produce good pastures in the rest of the state and how, if possible, to improve the bluegrass pastures of central Kentucky.

The high phosphorus and calcium content of the soil of central Kentucky is believed to be fundamentally responsible for the excellent pastures in that region. The better pastures are on soils ranging in phosphorus from 3,000 to 20,000 pounds and more in 2,000,000 pounds of soil, the average being perhaps 7,000 pounds. The phosphorus is chiefly in the form of tricalcium phosphate, assuring an abundant supply of nutrient calcium as well as of phosphorus. Other minerals, while not so high proportionately are abundant. The total nitrogen content is about 4,000 pounds.

It appears that legumes have been indispensable in the production of the pastures of central Kentucky for reasons presented in this paper, and that the legumes have had that part because of the mineral content and favorable reaction of the soils. This combination has produced famous pastures. Can they be duplicated elsewhere? We know that by the liberal use of limestone and phosphate on most soils of Kentucky, good pastures of grasses and legumes can be produced.

Finally, can highly productive pastures such as those of central Kentucky be improved, especially for more intensive pasturing? That cannot be answered yet, though there is evidence that they can be. Studies pertaining directly to pastures have been in progress only about 10 years, and some of these studies are necessary to a proper perspective. Time is a very important element in pasture studies because nature must be given time to show her reaction to our efforts.

THE RELATIVE SEED YIELDS IN DIFFERENT SPECIES AND VARIETIES OF BENT GRASS[1]

H. F. A. NORTH AND T. E. ODLAND[2]

SINCE the close of the World War the growing of fine bent grass for seed has spread rapidly from Germany to New Zealand, Rhode Island, the Maritime Provinces in Canada, the Pacific Northwest, and to New Jersey. The production of fine bent seed was a thriving industry at an earlier period in Rhode Island as well as in much of New England and New York. Much of the acreage of bent harvested for seed at present is found in naturalized stands. Practically pure stands of colonial and creeping bents are frequently found. Naturalized stands of velvet bent are found infrequently and usually consist of mixtures with other bents. The bents, and especially Rhode Island colonial bent, have been planted in Rhode Island for a number of years in order to produce purer seed and larger yields than are usually obtained from naturalized stands.

Redtop early became naturalized in southern Illinois where a large part of the seed is now produced. Fine bents are frequently the dominant grasses in pastures and reverting meadows in the more humid parts of the northern states. They form most beautiful lawns in this region. Almost all putting greens in this territory are composed largely of bent grasses. The various geographic sections of the United States have been found to favor different bent grasses.

There are many new strains of the bent grasses which have been tested during recent years and a variety of superior kinds are now available for the vegetative planting of putting greens or lawns. Growers of bent seed are faced with many problems as they attempt to grow the new strains for seed. Rhode Island farmers have been able to produce satisfactory yields of colonial bents and fair yields of velvet bent, but have had only indifferent success with creeping bent seed production.

LITERATURE CITED

Burlison and others (1)[3] state that redtop in Illinois is a crop that will maintain a stand for a number of years, depending on the fertility of the soil and the use made of the crop. The duration of the stands varied from 3 to 15 years with an average of 6 years. Lime and phosphorus were found to increase markedly both the yield of seed and of hay. The crop was found to mature seed approximately July 15 and to shatter badly after 10 days or more beyond this date. It is recommended that the crop be harvested for seed not later than one week after blooming is completed. Yields of redtop averaged 54 pounds per acre during the period from 1922 to 1932 and varied from an average of 30 pounds per acre in 1925 to 75 pounds in 1927.

[1]Contribution from the Department of Agronomy, Rhode Island Agricultural Experiment Station, Kingston, R. I. Also presented at the annual meeting of the Society held in Washington, D. C., November 23, 1934. Published by permission of the Director of Research as Contribution No. 469 of the Rhode Island Agricultural Experiment Station. Received for publication February 16, 1935.

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[3]Figures in parenthesis refer to "Literature Cited," p. 383.

An excellent summary of literature pertaining to the bent grasses has been made by Lewis (5, 6). Odland (9), Edler (2), Schoth (10), and LeLacheur (3) describe the growing of fine bent for seed in various important producing areas. Yields of 30 to 60 pounds of seed per acre are quoted by LeLacheur for Prince Edward Island and New Brunswick. The yield in Oregon according to Schoth varied between 50 and 75 pounds, and a yield of 75 pounds of colonial bent per acre has been reported as an average of two years for New Zealand. This is somewhat higher than the average according to Lewis (6). The work of Levy and Saxby (4) shows that seed is harvested in New Zealand largely by stripping.

EXPERIMENTAL

In 1928, experiments were begun by the Rhode Island Agricultural Experiment Station for the purpose of determining the suitability of a number of bent grasses for seed production. In general, the kinds included were those of which it was thought that there would be a demand for seed if it were available.

A comprehensive selection of bent grass seeds and stolons was obtained and planted in turf plats. Redtop, types of colonial bent, creeping bent (stolons and seed), and strains of velvet bent were included. The results of a 3-year comparison of putting quality of the turf produced by these different strains and varieties have been reported by North and Odland (7). Some of the more promising or important of these bent grasses were planted for testing under seed production.

The seed production test included 12 different grasses, each planted in quadruplicate plats 30¼ feet by 10 feet, or 1/144-acre each. Narrow cultivated paths separated the different plats. The plats were edged each season. Except for watering, weeding, and roguing soon after planting, the plats were kept as near as possible under field conditions such as might exist under commercial growing. Some water was used in order to obtain satisfactory stands when plantings were made in unfavorable seasons.

The plats were rolled in late March or early April. All plats were fertilized uniformly in early spring as shown in Table 1.

TABLE 1.—*Fertilizer and lime applied to bent grass varieties for seed production, 1929 to 1934.*

Fertilizing materials	Nutrients (N, P_2O_5, K_2O) applied in pounds per acre						
	1929	1930	1931	1932	1933	1934	Av.
Sulfate of ammonia (N).....	100	90	60	60	60	60	72
Superphosphate (P_2O_5)......	75	90	90	90	90	90	87
Muriate of potash (K_2O)....	75	75	75	45	45	45	60
Limestone................	—	—	—	1,000*	—	—	167

*CaO neutralizing equivalent.

Some of the grasses lodged badly during the season of 1930. In order to reduce lodging the applications of nitrogen were decreased from 90 to 60 pounds per acre in subsequent years. Evidence from an adjoining fertilizer experiment on colonial bent (8) indicated that potash applications were unnecessarily high. Accordingly, the acre application was reduced from 75 to 45 pounds of potash in 1932. Lime was applied to all plats in the spring of 1932.

The soil where the experiment was conducted is a moderately fertile silt loam underlain with gravel. Tests of several plats in the area in late autumn have shown

a range of acidity as follows: 1930, pH 4.34 to 4.53; 1932, pH 4.54 to 4.99; and 1933, pH 4.15 to 4.50. A composite sample of the area tested pH 4.45 in November 1934. Obviously, the soil was highly acid during much of the period.

Notes were taken each year on stand, heading, mixture, weeds, and ripening. The grasses were cut with a scythe, cured partially in the swath, shocked, and covered with canvas hay caps. After a thorough curing, the crop was packed into wool bags for storage until air dry and until a time convenient for threshing. Threshing was delayed usually until October or November. The seed was flailed out in 1930, while in the following years a small thresher was used. In order to remove a larger part of the straw a special straw rack was constructed for the thresher which had finer perforations than that used for cereals. No air blast was used during threshing.

Considerable time was consumed in working out the technic of cleaning the seed. Special screens and careful regulation of the air blast were found highly important. Actual yields per plat in grams of cleaned seed were calculated to pounds per acre. The weight per bushel of the seed obtained was determined during the period from 1930 to 1933.

RESULTS

The appearance and growth habit varied widely between the bents. In Table 2 will be found data on the stand in early spring and the height, date, and amount of lodging when ripe. For the most part the figures represent an average of 20 estimates and should be fairly accurate. The percentage scores for putting quality cover four seasons.

Stands of 90 to 100% are considered good, those in the 80's fair, and below 80 poor. Satisfactory stands have persisted in redtop, the colonials, and in some strains of velvet bent. Stands of creeping bent either died out, became weedy, or became mixed with colonial and velvet bents. Seaside creeping bents tended to show larger amounts of bent mixture than the stolons. Some of these plats were dug up in 1931 because they were heavily mixed with colonial bent. Redtop, colonial, and the velvet bents were relatively free from weeds and mixture depending somewhat upon the stand.

Redtop was found to grow to approximately three times the height of Washington creeping bent. Metropolitan and Virginia were short also, while the seaside creeping bent grew approximately as tall as the colonial bents. Among the velvet bents, No. 14,276 was tall, Highland intermediate, and Kernwood rather short.

The colonials and redtop have ripened earlier in general than the creeping bents and the latter somewhat earlier than the velvet bents. Almost as much difference in time of ripening was found between strains within a species in creeping and in velvet bent as was found between two species such as colonial bent and creeping bent. The dates of ripening recorded in 1930 and 1931 were considerably later than those during 1932 and 1933. It is this difference which accounts for the apparent lateness of two of the samples of seaside creeping bent tested as compared with the third. Many of the grasses lodged during 1930 and 1931, probably as a result of the high applications of nitrogen at that time. Lodging was found to be progressively heavier in the species as follows: Creeping bent, colonial bent, redtop, and velvet bent.

The scores for the same grasses in putting green turf varied from 44% for Virginia creeping to 88% for No. 14,276 velvet bent. The velvet and colonial bents scored higher than did the creeping bents. The ratings for quality of turf have been much the same for the seed and vegetative plantings of those strains of creeping and velvet bent in which both plantings have been made. The quality of turf from the plat-grown seed compared favorably also with the quality of the turf from original seed in colonial and seaside creeping bents.

TABLE 2.—*Data on the growth of different bent grasses grown for seed, average, 1930 to 1934.**

Species and type or strain	Stand %	Height in inches	Date ripe	Lodging %	Lodging Degree	Score of turf, 1931–34, %
Redtop (*A. alba*)	97	32	July 27	21	32	*45*
Colonial (*A. tenuis*):						
Type a, Rhode Island	100	21	July 28	15	17	79
Type b, Astoria	98	21	July 26	24	27	79
Type c, Oregon bent†	*99*	*20*	*July 21*	*0*	*0*	79
Creeping (*A. palustris*):						
Metropolitan stolons	96	13	July 30	6	11	71
Virginia stolons	68	13	Aug. 4	12	11	44
Washington stolons	78	11	Aug. 3	4	1	66
Seaside:						
Coos Co., Ore., seed	*96*	*24*	*Aug. 7*	*9*	*14*	69
Marshfield, Ore., seed	*98*	*25*	*Aug. 7*	*4*	*4*	60
Oregon, seed	*98*	*19*	*July 24*	*1*	*4*	67
Velvet (*A. canina*):						
Highland stolons	83	17	Aug. 4	27	18	80
Kernwood stolons	96	16	Aug. 7	35	26	86
B. P. I. 14,276 stolons	91	23	Aug. 6	43	49	88
Yorkshire stolons	68	18	Aug. 6	34	42	72

*Figures in italics are for 2-year averages only.
†Name in Oregon. In New Zealand it is called dryland browntop.

In Table 3 will be found the yields of cleaned seed each season and the average yield for the period of 1930 to 1934.

Redtop yielded more than any of the fine bents each year except the last and averaged 217 pounds of seed per acre. This is nearly four times the average yield reported for the area in Illinois where it is produced commercially.

The yields of Rhode Island colonial varied from 47 to 264 pounds per acre and averaged 114 pounds. It was out-yielded by Astoria colonial bent. Oregon bent formed a more open growth and yielded significantly less seed than the representatives of types a and b colonial, although it remained relatively pure.

Among the strains of creeping bent, Metropolitan and Virginia were found about equal and both higher in seed-yielding ability than Washington creeping bent. Stands of Washington creeping bent have been somewhat less permanent than stands of the other two strains, although all of the strains became mixed or died out after two or

TABLE 3.—*Yields of recleaned seed of different bent grasses during the period of 1930 to 1934.*

Species and type or strain	Method of planting	Cleaned seed, pounds per acre					
		1930	1931	1932	1933	1934	Average
Redtop (*A. alba*)	Seed	356±35	157±19	293±30	160±16	117±10	217±11
Colonial (*A. tenuis*):							
Type a, Rhode Island	Seed	264±26	82±10	104±11	47± 5	73± 6	114±6
Type b, Astoria	Seed	310±31	97±12	110±12	76± 7	94± 8	137±7
Type c, Oregon bent	Seed	—	—	—	100±10	23± 2	62±5
Creeping (*A. palustris*):							
Metropolitan	Stolons	—*	—†	231±24	68± 6	63± 5	121±8
Virginia	Stolons	275±27	39± 5	26± 3	—*	—*	113±9
Washington	Stolons	153±15	12± 1	—*†	75± 7	47± 4	72±4
Seaside:							
Coos Co., Ore.	Seed	178±17	80±10	—‡	—	—	129±8
Marshfield, Ore.	Seed	122±12	88±11	—‡	—	—	105±8
Oregon	Seed	—	—	—	60± 6	67± 6	63±4
Velvet (*A. canina*):							
Highland	Stolons	152±15	127±15	158±17	77± 7	141±12	131±6
Kernwood	Stolons	129±13	26± 3	118±12	58± 6	63± 5	79±4
B. P. I. 14,276	Stolons	34± 3	26± 3	85± 9	57± 6	86± 7	58±3
Yorkshire	Stolons	—	10± 1	24± 2	—*	—*	17±1

*Crop failure.
†Replanted.
‡Replanted; changed to new variety; badly mixed.

three seed crops. It was unfortunate that such a great amount of mixture with colonial bent occurred in the seaside creeping bents since on this account the yields are not representative. The average yields for 2 years indicate that seaside creeping bents yielded considerably less than the colonial bents.

The average yield among the velvet bents ranged from 17 pounds per acre for Yorkshire to 131 pounds for Highland. The consistently high yields of Highland are responsible for its rank slightly higher than Rhode Island colonial. The yields of the other velvet bents were very low in 1931 and as an average of the five crops were considerably below the colonials. Yorkshire yielded very poorly and did not persist well in seed production.

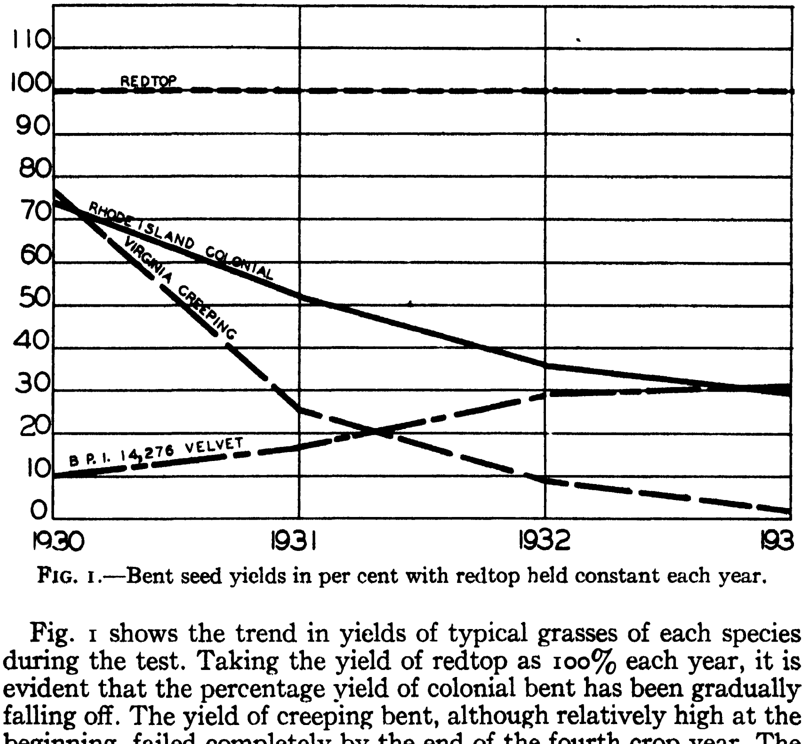

FIG. 1.—Bent seed yields in per cent with redtop held constant each year.

Fig. 1 shows the trend in yields of typical grasses of each species during the test. Taking the yield of redtop as 100% each year, it is evident that the percentage yield of colonial bent has been gradually falling off. The yield of creeping bent, although relatively high at the beginning, failed completely by the end of the fourth crop year. The velvet bents have shown a more or less pronounced trend upwards in relation to redtop. Velvet bent B. P. I. No. 14,276, has shown gradual improvement and finally produced a larger yield than Rhode Island bent by the end of the period.

It has been shown in this and other experiments that creeping bents are much more sensitive to acid soil conditions than are colonial and velvet bents. Velvet bents have been found more tolerant of such soil conditions than the colonial bents. These facts may explain in a large measure the difference between the trends in yield.

QUALITY OF SEED

An effort was made to clean the seed from each plat uniformly and to obtain a marketable product. As a check on the quality, the weight per bushel of the cleaned seed of each variety was determined each year. Germination and purity tests were made in the local laboratory and also on a few samples by submitting them to the Rhode Island State Department of Agriculture for official test.[4] The velvet bents were cleaned on the same machine each season, while other varieties were cleaned on a larger machine of the same type. The operators were the same during the period of 1931 to 1934. Data on weight per bushel for the different varieties are shown in Table 4. The figure for each season represents the average of quadruplicate plats.

TABLE 4.—*Weight per bushel of recleaned seed of different bent grasses grown during the period of 1930 to 1934.*

Species and type or strain	Pounds per bushel					
	1930	1931	1932	1933	1934	Average
Redtop (*A. alba*)	25.9	21.2	27.1	26.3	21.7	24.4
Colonial (*A. tenuis*):						
Type a, Rhode Island	28.6	20.9	30.6	27.0	20.5	25.5
Type b, Astoria	25.6	21.9	28.7	29.1	25.7	26.2
Type c, Oregon Bent	—	—	—	27.1	20.2	23.6
Creeping (*A. palustris*):						
Metropolitan stolons	—	—	26.6	26.5	22.5	25.2
Virginia stolons	21.2	22.0	30.7	—*	—	24.6
Washington stolons	20.6	24.1	—	28.2	25.0	24.5
Seaside:						
Coos Co., Ore., seed	27.2	22.4	—	—	—	24.8
Marshfield, Ore., seed	24.8	20.3	—	—	—	22.5
Oregon, seed	—	—	—	28.4	22.2	25.3
Velvet (*A. canina*):						
Highland stolons	19.2	19.4	25.4	22.4	22.5	21.8
Kernwood stolons	21.9	22.6	29.3	22.9	23.2	24.0
B. P. I. 14,276 stolons	20.8	19.6	24.4	29.5	26.1	24.1
Yorkshire stolons	—	14.4	21.4	—	—	17.9

*Insufficient volume for determination.

In general, a high weight per bushel is correlated with a high proportion of seed in relation to yield of hay. Hay yields have remained more constant than seed yields. The latter varied considerably from year to year. The average weights per bushel for the period tend to be lower for the velvet bent seed than for that of the other kinds. This may be due in part to a necessary reduction in the air blast used in cleaning the velvet bent seed. The velvet bent seeds are very small and only a light air blast can be used. The seed of Kernwood and of

[4]Credit is due F. A. McLaughlin, Massachusetts State Seed Analyst, for making the tests of samples submitted through the Rhode Island State Department of Agriculture. The authors are also indebted to M. H. Brightman of the Rhode Island Department of Agriculture for arranging for these tests to be made.

No. 14,276 were heavier each year than that of Highland velvet bent. Yorkshire was very low, both in weight per bushel and in yield. Redtop, colonial bents and creeping bents had approximately the same average weight per bushel.

There are a number of factors which tend to reduce the weight per bushel of the seed, although the speed, screens, and air blast are held constant in the cleaning process. Some of the more important factors are as follows: Immature seed, large perforations in the thresher screens, hasty cleaning, and retaining double-hulled seeds. Smutted seeds have not reduced weight per bushel to any great extent thus far. The weight per bushel has varied from 14 to 30 pounds per bushel and has averaged approximately 25 pounds. The highest quality of bent seed on the market will weigh 30 pounds per bushel or over.

Table 5 shows a comparison of analyses and weight per bushel of the samples submitted for official test.

TABLE 5.—*Purity and germination tests of seed of certain bents during the period of 1931 to 1933.*

Year	Plat	Purity %	Weeds %	Inert %	Other crop seeds %	Germination %	Weight per bushel, lbs.	Remarks
				Kernwood Velvet Bent				
1931	B-46	63.0	Trace	37.0	None	83	25.5	
1932	B-46	96.5	0.01	2.9	0.5	92	29.7	
1933	B-46	79.8	0.02	18.9	1.2	68	19.5	Much smut
				Rhode Island Colonial Bent				
1931	B-6	91.8	Trace	8.1	None	88	21.3	
1932	B-6W	98.9	0.02	1.0	Trace	94	30.2	
1933	B-6W	94.2	0.03	3.9	1.8	60	27.5	Much smut
				Virginia Creeping Bent				
1931	B-3	80.0	Trace	19.0	1.0	87	19.4	
				Washington Creeping Bent				
1933	B-1W	86.4	7.0	4.7	2.8	87	31.0	No disease
				Metropolitan Creeping Bent				
1932	B-45	75.0	0.07	1.9	23.0	93	26.0	
1933	B-45	70.9	0.02	6.5	22.6	82	26.0	Few smutted

Comparisons of purity and weight per bushel indicate that considering the sum of pure seed and other crop seeds in the sample that bent seed weighing about 30 pounds per bushel will test approximately 98% pure. In a similar way, seed weighing 20 pounds will test approximately 80% pure. A more complete set of analyses are needed in order to approximate the purity of samples between these extremes in weight per bushel.

The tests show that weed seeds had been largely removed during cleaning. The percentage of inert material varied considerably and tended to be low in 1932, a year when the seed yield was high, and high in 1931 when the yield was low. "Other crop seed" consisted

entirely of bent seed of other kinds. The velvet and colonial bents had small amounts in the fourth seed crop, while creeping bents showed a much larger amount by that time.

The percentage of germination was satisfactory except for the velvet and colonial bent samples of 1933. The low germination of this was largely due to smut. It is notable that creeping bent seed was relatively free from smut and germinated reasonably well.

SUMMARY AND CONCLUSIONS

The fine bent grasses have been found eminently adapted for putting greens over much of the northern half of the United States Fine bents have formed beautiful and enduring lawn turf in New England since colonial times, and more recently have been found valuable in a variety of sports turf.

The growing of these grasses for seed has become an important industry in certain sections of this country. Very little investigational work on the problems of bent seed production has been reported. Results of experimental work at the Rhode Island Agricultural Experiment Station on seed production of different species and varieties of bent grass are reported in this paper.

Experiments were begun for the purpose of obtaining an estimate of the yield of seed that might be expected under commercial production and at the same time to discover how closely the seeded turf would resemble the turf from a vegetative planting in a number of strains. Other experiments that have been reported in previous publications concerned fertilizer tests on colonial bent grown for seed and the relative value of the different bents for golf greens.

It has been shown that the turf from seed and the turf from vegetative planting in a strain tend to become very similar in putting quality.

Quadruplicate plats were planted with 12 different bent grasses and satisfactory stands were secured. The species included were *Agrostis alba*, *A. tenuis*, *A. palustris*, and *A. canina*. Rather high levels of fertility were maintained. Tabular data on the growth and yield of recleaned seed are presented for the years 1930 to 1934.

Colonial and velvet bents were found to continue relatively free from weeds and mixtures in practically full stands. Although mixing with colonial bent was evident in plats of redtop before lime was applied, the stands continued relatively pure.

Stands of creeping bent were short lived and permitted of invasion by weeds and other bent grasses.

The yield of seed varied widely from year to year and varied also among the grasses. The average yield of seed for the period varied from 58 pounds per acre for B. P. I. 14,276 velvet bent to 213 pounds for redtop. Astoria colonial out-yielded Rhode Island colonial by about 20%. Highland velvet bent yielded about 15% more than Rhode Island colonial.

Based upon the seed yield of redtop, there was a gradual downward trend in the percentage yield of the colonials, a gradual upward trend in velvet bents, and a rapid downward trend in creeping bents.

The experiments indicate that the improved vegetative strains of velvet bent can be successfully grown for seed production, but that the stolon strains of creeping bent are more difficult to grow for this purpose.

The high quality of velvet bent turf for the putting green and lawn may be expected to increase the demand for the seed. Seed of exceptional strains, such as B. P. I. 14,276 and Kernwood, should command a special premium in price.

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AN ANALYSIS OF SOIL AND SEASONAL EFFECTS IN ALFALFA VARIETY TESTS[1]

H. M. TYSDAL[2]

DURING recent years considerable interest has been attached to field experimental technic as evidenced by the 1933 report and bibliography of the committee of the American Society of Agronomy on standards for the conduct and interpretation of field and lysimeter experiments. An opportunity has been given the writer to analyze certain phases of alfalfa varietal testing, and, alfalfa being a perennial crop, the results may indicate certain problems which are not apparent in the testing of annual crops.

Two problems have been investigated in the present paper concerned with alfalfa testing, *viz.*, the number of years required to determine relative yields for a given set of plats, involving the question of differential response to season; and the relative importance of "place effect" in field trials of this crop. The term "place effect" is not used in the sense of regional effect, but rather in the sense of field heterogeneity on the same farm. Although variety tests from four different states are used, no attempt has been made to study the varieties, as such, in different regions of the country. The different stations were chosen chiefly to determine if conclusions from tests in one region of the country would or would not substantiate those from other regions.

METHODS

Through the courtesy of the various cooperating institutions, detailed data of the yields of replicated plats of alfalfa varieties were obtained for this anlaysis. Since the yield of the varieties, as such, are not concerned, the detailed data are not given, but information is presented in Table 1 to give an adequate understanding of the amount of data upon which the calculations are based.

The relative stand of plants is no doubt a factor in the present study, but an analysis of its relation to production is impossible with the data at hand. Care was taken to omit those varieties from consideration where the stand was obviously too thin for maximum production since those varieties which thin out rapidly demonstrate their undesirability and yield data are unnecessary. In all tests analyzed systematic replication was the rule, and objections may be raised to using certain statistical methods on systematic distributions. It is believed,

[1]Contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, and the Nebraska Agricultural Experiment Station, Lincoln, Nebr., cooperating. Published as Journal series paper No. 157 of the Nebraska Agricultural Experiment Station. Also presented at the annual meeting of the Society held in Washington, D. C., November 22, 1934. Received for publication February 14, 1935.

[2]Associate Agronomist, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. It is a pleasure to acknowledge the courtesy and cooperation of the men in charge of alfalfa investigations at the experiment stations at Holgate, Ohio; Manhattan, Kans.; Lincoln, Nebr.; and Redfield, S. D.; cooperating with the Division of Forage Crops and Diseases, and to H. L. Westover and E. A. Hollowell of the latter division through whom it was possible to obtain the data necessary for the analysis. The author is also indebted to F. R. Immer for criticism of the manuscript.

however, that the methods herein applied probably can be as readily justified as other methods of statistical procedure.

Two methods of analysis are used, the zero order correlation coefficient and Fisher's analysis of variance. The correlation coefficient is used to measure the relative consistency of 1 or 2 year's yields compared to the final yield as determined over a period of years. It is also used to measure the relative importance of seasonal and place effect. The analysis of variance is used chiefly to determine the relative importance of seasonal and place effects. In addition a paired comparison is used in comparing check plats in the same test over a period of years to show place effect differences.

Throughout the paper the terms "relative yield" or "relative rank" are used. Particular attention is drawn to these terms because, although the actual yields of varieties may vary greatly from year to year, it is the relative yield from year to year which is here being considered. The relative rank, after all, determines the correct evaluation of varieties.

TABLE 1.—*Description of fields and tests from which data were obtained.*

Location	Field No.	No. of varieties	No. of replications*	Date planted	No. of years tested	Remarks
Redfield, S. D.	—	39	2	Various	4	Upland
Lincoln, Nebr.	1–3	68	3	Various	5	Upland
Lincoln, Nebr.	5	35	2	1930	3	Upland
Manhattan, Kans.	A	38	2	1930	3	Upland
Manhattan, Kans.	F	38	2	1930	3	Bottomland
Holgate, Ohio	A	37	3	1929	3	Level land
Holgate, Ohio	B	37	3	1930	3	Level land

*All tests were laid out in systematic distribution, with check plats of a standard variety every 3rd, 4th, 5th, or 6th plat.

RESULTS

CORRELATION OF 1 OR 2 YEAR'S YIELD WITH SEVERAL YEARS' YIELDS

The mean varietal yields for each year were correlated with the mean yield for the total number of years the varieties were under test. The yields were also grouped as, for example, the first 2 years or the last 2 years, and correlated with the final yield. The results for seven different fields, representing 292 lots and 2,220 individual annual plat yields, are given in Table 2.

In general, all correlation coefficients are high, but the first and last years are less consistent than the second year. Lack of being well established may account for the low correlations the first year. At the Redfield, S. D., station there is a negative correlation between the first year's yields and the 4-year average. This is probably due to combining different fields and different planting dates with resulting variations in yielding ability for a given year. When all yields at Redfield were computed to a relative basis a positive correlation coefficient of .653 resulted instead of the negative correlation of —.385. Since all other correlations are based on actual yields, the negative correlation is left in Table 2. Considering only the second year, all fields have a .9 correlation or higher when compared with the average

yield of 3 or 4 years. When the first 2 years or the second and third years are combined and correlated with the final averages, all coefficients are high, there being only 2 out of the 14 which are lower than .93. When it is considered that there is variability and error connected with the determination of each individual yield, these correlation coefficients are very significant and, as will be noted in the discussion, lead to the conclusion that probably 2 years' yield determinations are sufficient for ranking varieties for yielding ability. It may be noted that Redfield, S. D., having the lowest precipitation, has the lowest correlations, while Holgate, Ohio, having the highest precipitation, has the most consistent and highest correlations.

TABLE 2.—*Summary of correlation coefficients showing the relation between 1 or 2 year's production and the average production over a period of years.*

Mean yield for all years correlated with yield of	Red-field, S. D.	Lincoln, Nebr.		Manhattan, Kans.		Holgate, Ohio	
		1-3	5	A	F	A	B
1st year....	—.385	.850	.739	.793	.942	.929	.953
2nd year....	.927	.940	.904	.922	.953	.971	.974
3rd year....	.651	.927	.659	.895	.466	.976	.948
First 2 years	.713	.979	.959	.976	.976	.992	.986
2nd and 3rd years.....	.947	.964	.892	.934	.952	.995	.980

Certain objections may be raised to correlating 1 or 2 year's results with the average of 3 years, when the latter is partly made up from the first two. This procedure is felt to be justified in that the final ranking of the varieties in an ordinary test is based on the 3 or 4 years' yield (as the case may be) and our present object is to determine how divergent are the results from 1 or 2 year's test. This can be determined only by comparing the result of 2 years' yield with the final yield as determined over a longer period of years.

Naturally, it is also of interest to obtain correlations, for example, of the first year with the second and of the second with the third. This has been done for two locations and the results tabulated in connection with the comparison of seasonal and place effects in the first part of Table 4. Even when individual years are correlated the correlations remain high in four out of six cases. The low correlation on field F at Manhattan between the years 1932 and 1933 can be largely explained by the fact that bacterial wilt had decidedly thinned some of the stands by 1933, resulting in a decreased yield for these plats. The correlation of field A, Manhattan, for 1931 and 1932 is possibly low because the alfalfa had not become fully established on the upland.

COMPARISON OF SEASONAL AND PLACE EFFECTS

An analysis of variance was made for the data from three different stations to determine if the variability due to years was greater or less than that due to replications. In order to present more clearly

the various steps involved in arriving at the variance table, Example 1 is given showing the detailed calculations for a hypothetical setup involving three varieties each having three replicates and tested for 4 years. The example shows the manner of obtaining the variance of the interaction of varieties and years and that of varieties and replicates, which are of most interest in the present analysis.

EXAMPLE 1.—*Calculation of variance using three varieties with three replications and tested for 4 years.*

Year	Yield of varieties A, B, and C, by plats															Tota by years
	Variety A			Total by var.	Variety B			Total by var.	Variety C			Total by var.	Total by replicates			
	Replicate				Replicate				Replicate							
	1	2	3		1	2	3		1	2	3		1	2	3	
1929	4.2	3.5	3.7	11.4	4.8	4.2	3.8	12.8	3.4	3.8	3.9	11.1	12.4	11.5	11.4	35.3
1930	3.6	3.2	3.5	10.3	4.3	4.0	3.9	12.2	3.0	3.2	3.2	9.4	10.9	10.4	10.6	31.9
1931	4.5	3.8	3.9	12.2	5.0	4.8	4.2	14.0	3.8	4.0	4.1	11.9	13.3	12.6	12.2	38.1
1932	4.0	3.6	4.0	11.6	4.6	4.5	4.0	13.1	3.6	3.0	3.7	10.3	12.2	11.1	11.7	35.0
Totals	16.3	14.1	15.1	45.5	18.7	17.5	15.9	52.1	13.8	14.0	14.9	42.7	48.8	45.6	45.9	140.3

Mean = 3.89722

Calculation of Sums of Squares*

$$\text{Between varieties} = \frac{45.5^2 + 52.1^2 + 42.7^2}{12} - (140.3 \times 3.89722) = 3.88$$

$$\text{Between years} = \frac{35.3^2 + 31.9^2 + 38.1^2 + 35.0^2}{9} - (140.3 \times 3.89722) = 2.14$$

$$\text{Between replicates} = \frac{48.8^2 + 45.6^2 + 45.9^2}{12} - (140.3 \times 3.89722) = .52$$

Total between varieties and years =

$$\frac{11.4^2 + 10.3^2 + 12.2^2 + 11.6^2 + 12.8^2 \text{ etc.}}{3} - (140.3 \times 3.89722) = 6.22$$

Interaction of varieties and years = difference = 6.22 — (3.88 + 2.14) = .20

Total between varieties and replicates =

$$\frac{16.3^2 + 14.1^2 + 15.1^2 + 18.7^2 \text{ etc.}}{4} - (140.3 \times 3.89722) = 5.65$$

Interaction of varieties and replicates = difference = 5.65 — (3.88 + .52) = 1.25

Total between years and replicates =

$$\frac{12.4^2 + 11.5^2 + 11.4^2 + 10.9^2 \text{ etc.}}{3} - (140.3 \times 3.89722) = 2.80$$

Interaction of years and replicates = difference = 2.80 — (2.14 + .52) = .14

$$\text{Total} = \frac{4.2^2 + 3.5^2 + 3.7^2 + 3.6^2 \text{ etc.}}{1} - (140.3 \times 3.89722) = 8.61$$

Remainder = difference = 8.61 — (3.88 + 2.14 + .52 + .20 + 1.25 + .14) = .48

EXAMPLE NO. 1.—*Continued.*

Source of variation	Degrees of freedom	Sum of squares	Mean square
Between varieties	2	3.88	1.940
Between years	3	2.14	.713
Between replicates	2	.52	.260
Interaction of varieties and years	6	.20	.033
Interaction of varieties and replicates	4	1.25	.313
Interaction of years and replicates	6	.14	.023
Remainder†	12	.48	.040
Total	35	8.61	

*The various sums of squares are obtained by squaring the total yield of each of the varieties, years, or replicates, summating, dividing by the number of unit plats contributing to each total, and subtracting the product of the total of all plats times the average of all plats.

†The generalized error of the experiment is obtained from the interaction of varieties and replicates. The standard error of a single plat for a single year in this example would be $\sqrt{.313} = .559$.

Variance for the three locations is found in Table 3. Without exception, the variance due to interaction of varieties and replicates is larger than that due to interaction of varieties and years, and in two cases, significantly larger as determined from the table of significance presented by Snedecor.[3] To examine more carefully into what this means, it needs only to be pointed out that if there was perfect correlation of relative yields between varieties in each of the replicates there would be no "interaction", but if variety A, for example, yields high in replicate 1 and low in replicate 2 while variety B yields low in replicate 1 and high in replicate 2, presumably largely due to soil heterogeneity, the interaction of varieties and replicates would be very great. Similarly, with interaction of varieties and years, if the varieties have the same relative rank one year with the next, there would be very little or no interaction. Thus, the fact that the interaction due to replication is greater than that due to years suggests that improvement in alfalfa varietal testing should first come in the matter of correcting for variations due to soil and related errors.

In replicated varietal tests at Manhattan, Kans., and Holgate, Ohio, the same varieties were planted on two different areas of land, in Kansas the same year and at Holgate in successive years. This arrangement makes it possible to compare the yield of the same varieties the same year on two different fields and the yield of the same varieties on the same field for different years. Altogether there were six such comparisons of year with year and five of field with field, the correlation coefficients of which were averaged by Fisher's method.[4]

The results, given in Table 4, show that the average correlation of yields from the same plats in different years is .7563, while that of results from different fields in the same year is .6194. By Fisher's z test these correlations are significantly different. In these comparisons the means of the replicates were used, not the individual plats. If the

[3]SNEDECOR, GEORGE W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa : Collegiate Press, Inc. 1934.

[4]FISHER, R. A. Statistical Methods for Research Workers. Edinburgh : Oliver and Boyd. Ed. 4. 1932.

individual plats are taken, the difference between the correlations is much greater. Field F in Kansas with two replications, for example, has a correlation of .8265 between years, whereas it is only .5804 between individual plats planted to the same variety. On the other hand, with a larger number of replications there would probably be less difference. The fact that there is higher correlation between

TABLE 3.—*Variance analysis of alfalfa variety tests at Lincoln, Holgate, and Manhattan.*

Source of variation	Degrees of freedom	Sum of squares	Mean square
Field 3, Lincoln, 30 Varieties, 3 Replications, 5 Years			
Between varieties	29	7.40	.255
Between years	4	507.51	126.880
Between replicates	2	1.44	.720
Interaction of varieties and years	116	16.25	.140
Interaction of varieties and replicates	58	8.31	.143
Interaction of years and replicates	8	5.17	.646
Remainder	232	29.04	.125
Total	449	575.12	
Range A, Holgate, 37 Varieties, 3 Replications, 3 Years			
Between varieties	36	32 98	.916
Between years	2	310.82	155.410
Between replicates	2	.70	.350
Interaction of varieties and years	72	5.79	.080
Interaction of varieties and replicates	72	8.33	.116
Interaction of years and replicates	4	1.63	408
Remainder	144	23 11	.160
Total	332	383.36	
Field F, Manhattan, 38 Varieties, 2 Replications, 3 Years			
Between varieties	37	32 50	.878
Between years	2	111 86	55.930
Between replicates	1	1.53	1.530
Interaction of varieties and years	74	16 16	.218
Interaction of varieties and replicates	37	14.36	.388
Interaction of years and replicates	2	.67	.335
Remainder	74	4.96	.067
Total...	227	182 04	

the relative yield of varieties from year to year than from field to field in the ordinary test having one, two, or three replications emphasizes the fact that there may be greater variability due to place effect than to seasonal differences in the testing of a perennial crop where varieties are on the same plats of ground year after year These results also corroborate those found by analysis of variance

The place effect also can be analyzed on the basis of check plats which were used in all tests reported. Checks chosen in each replicate falling beside a given variety and compared to another set of checks similarly chosen in another portion of the field of the same test were found to differ significantly in yield over a period of years by Student's odds. An additional test between the checks is obtained by using the

error found by the variance method (the interaction of varieties and replicates) to compare the yields of replicated check plats. In all tests for which variance was obtained it was possible to find replicated plats of the check differing significantly in yield.

TABLE 4.—*Correlation analysis of varieties on the same plats in different years and for the same years in different fields.*

Location	Field	Year	No. paired varieties	No. rep.	r	z	(n-3)	(n-3)z
Correlating Yields on the Same Plats in Different Years								
Holgate....	A	'31 with '32	11	3	.8688	1.328	8	10.624
Holgate....	B	'31 with '32	11	3	.9213	1.598	8	12.784
Manhattan.	A	'31 with '32	38	2	.5342	.596	35	20.860
Manhattan.	F	'31 with '32	38	2	.8817	1.383	35	48.405
Manhattan.	A	'32 with '33	38	2	.8947	1.445	35	50.575
Manhattan.	F	'32 with '33	38	2	.2988	.308	35	10.780
Combined correlation....					.7563	.9874	156	154.028
Correlating Yields from Different Fields in the Same Year								
Holgate....	A with B	1931	11	3	.6862	.841	8	6.728
Holgate....	A with B	1932	11	3	.6168	.720	8	5.760
Manhattan.	A with F	1931	38	2	.5998	.693	35	24.255
Manhattan.	A with F	1932	38	2	.8011	1.102	35	38.570
Manhattan.	A with F	1933	38	2	.3371	.351	35	12.285
Combined correlation....					.6194	.724	121	87.598

	r	z	(n-3)	Reciprocal
Years with years.......	.7563	.987	156	.0064
Fields with fields.......	.6194	.724	121	.0083
		.263±.121		.0147

DISCUSSION

The available data for the conditions studied indicate that 2 years' yield from alfalfa in its prime may give practically as reliable results with respect to yielding ability as a 3-, 4-, or 5-year average. This does not mean that the variety test should be confined to a 2 years' yield test, but it is suggested that yields can be taken for perhaps 2 years and observations regarding stand, diseases, etc., can be made over longer periods, possibly supported by controlled tests for such characters as cold resistance and reaction to certain diseases. This system of testing would involve the principle of segregating and interpreting the various factors or characters, such as yield, disease resistance, etc., which together go to make a good variety. Of what value are yields from varieties having only half a stand compared to others having a full stand? In determining the years to be used for the yield test care should be taken to see that the plants are fully established, and, on the other hand, undue thinning of the plats should not have occurred.

The results showing that with few replications (two or three) the variability due to soil is greater than that due to season, emphasizes that certain changes in field technic are desirable. It is probable that sufficient replication and proper distribution, the latter perhaps involving some form of a modified random distribution, would make for a distinct improvement. More frequent plantings would no doubt serve the same purpose as increasing the number of replications with few plantings. With the data at hand it has been impossible to consider such factors as number of replications or size and shape of plats. Such factors will no doubt have to be adapted to the conditions of each test in accordance with the best principles of plat technic. Check plat correction, for example, is sometimes used, but it is improbable that great improvement in accuracy of results can be obtained by including a large number of checks and retaining only one or two replications of the unknown varieties.

Observations of various investigators will enable them to determine for their own conditions if the suggested 2-year period is sufficient to obtain satisfactory varietal yields. If this proves to be the case more emphasis can be given to sufficient replication and proper distribution, so that with approximately the same expenditure better results can be obtained. A further advantage is the possibility of securing reliable yield data from outlying field plats where long-continued yield tests are now impractical. The data clearly indicate that long-continued tests from the same plats do not serve to compensate for errors due to soil heterogeneity, rather, these differences, amounting to errors, tend to accumulate from year to year and lend a false security to the results.

SUMMARY

The number of years of testing required to obtain a reliable index of yielding ability and the relative importance of place effect was studied in alfalfa variety trials conducted at the experiment stations at Redfield, S. D.; Manhattan, Kans.; Holgate, Ohio; and Lincoln, Nebr.

Correlation coefficients between 1 or 2 year's yield and the final yield were very high and judging from the data available for this study 2 years' yield results were practically as indicative of yielding ability as 3, 4, or 5 years' results.

Analysis of variance of alfalfa variety tests indicated greater variability due to place effect than to seasonal effect.

Variance and paired comparison analysis showed that significant differences between replicates of the same variety (the check) could be found in all tests. A higher correlation was found between yields of varieties one year with the next from the same plats than between two different fields for the same year planted to the same varieties, emphasizing the importance of field heterogeneity and that long-continued tests from the same plats do not serve to compensate for these errors.

THE EFFECT OF SOIL CONDITIONS AND TREATMENT ON YIELDS OF TUBERS AND SUGAR FROM THE AMERICAN ARTICHOKE (*HELIANTHUS TUBEROSUS*)[1]

H. B. SPRAGUE, N. F. FARRIS, AND W. G. COLBY[2]

THE American artichoke (*Helianthus tuberosus*),[3] which is native to the eastern half of the United States, has considerable potential value as a cultivated crop. Although closely related to the sunflower, the artichoke differs in that it produces tubers as the principal harvested portion. Improved cultivated varieties bear comparatively large tubers clustered near the main root in contrast with wild forms of artichokes which produce small tubers on long stems. The tubers are formed during late summer and autumn, and will store perfectly over winter when left in place in the field.

Artichoke tubers have been used rather extensively for both human food and feed for livestock in France and other European countries for at least a hundred years. Although attention has been directed to the artichoke occasionally in America, its poor storage qualities after harvest have impeded its adoption as a standard crop plant. Nevertheless, the tubers have been recognized locally as a valuable vegetable, and farm experience has substantiated the records of their high feeding value for hogs, dairy cows, and other livestock. Artichoke tubers are also an exceedingly important potential source of levulose sugar. Because of its superior sweetening value and high preservative effect as compared with ordinary cane sugar, levulose sugar has a high potential value in industry and commerce. Development of methods for factory-scale production of levulose from artichoke tubers, will permit exploitation of the crop for levulose manufacture. The present increasing use of artichoke tubers for human food as a vegetable warrants reports of tests on certain cultural practices which are of importance in growth of the crop.

Artichokes are credited with a very wide range of adaptation to both soil and climatic conditions. However, there are certain specific conditions that permit comparatively high yields of tubers and of inulin from which levulose is manufactured. More complete information on such conditions is necessary for profitable production of the crop.

EXPERIMENTAL PROCEDURE

The experiments reported herein were conducted with the improved white variety obtained from T. W. Wood & Sons at Richmond, Virginia. The tubers were cut and planted with a potato planter in early May in rows 3 feet apart,

[1]Contribution from the Department of Soils and Crops, New Jersey Agricultural Experiment Station, New Brunswick, N. J. Journal Series paper of the Agricultural Experiment Station. Received for publication February 28, 1935.

[2]Agronomist and Research Assistants in Agronomy, respectively.

[3]The name "Jerusalem artichoke," frequently applied to this plant, is somewhat misleading since "Jerusalem" is merely an old English corruption of "girasole," the Italian name for the sunflower, with which the artichoke was once confused.

using 8 to 10 bushels of tubers to plant an acre. The growing crop received three to four cultivations prior to July 15 by which time the plants shaded the area between the rows fairly completely. The plants continued vegetative growth until blooming took place in mid-September, and the tops remained green until heavy frosts occurred in October. The tops were then removed by mowing or cutting with a corn binder, and the tubers were dug in November with an ordinary potato digger. Tubers for seed were stored in the ground over winter and harvested the following April just prior to planting.

The field on which the lime and fertilizer experiments were conducted was Sassafras sandy loam which had earlier been cropped to general field crops and later to asparagus with scant fertilization. The fertility was near the average for this soil type under general farming. The individual plats were 50 feet long and 4 rows wide, with rows spaced 36 inches apart. Harvested yields were recorded on the center two rows of each plat. Check plats distributed throughout the field indicated fairly uniform fertility in the area chosen for the test, and the treatments were represented by duplicate plats. The analysis of variance showed that differences of 10.0% in average tuber yields of individual treatments were necessary for odds of 20 to 1. Smaller differences are of course significant when trends are indicated in series of treatments varying regularly in abundance of a single element.

Sugar determinations were made on fresh tubers, or on tubers which were placed in cold storage, and analysed as soon as possible thereafter. The analytical method in 1929 consisted of finely chopping the tubers, direct acid hydrolysis of the carbohydrate, and calculation of the total reducing sugars from weights of the cupric oxide produced by reduction of Fehling's solution with Munson and Walker's tables. In 1930 and 1931, fresh tubers were ground to a pulp from which separate samples were drawn for determinations of moisture and carbohydrates, respectively. The latter samples were acidified with hydrochloric acid and hydrolyzed for 40 minutes at 80°C. The resulting solution was cooled, clarified with lead acetate, made neutral with sodium hydroxide, and filtered. Total sugars were determined from the filtrate, using Lane and Eynon's method.[4]

TUBER YIELDS AS AFFECTED BY SOIL TEXTURE AND RAINFALL

Although the artichoke is tolerant of a wide range of soil texture, the yield of tubers is greatly influenced by this factor in unfavorable seasons. The performance of the crop on two soils is given in Table 1. The rainfall during the period of tuber formation, August 15 to October 15, was deficient in both years, showing an average slightly below half the normal precipitation of 8.0 inches. The low water-holding capacity of the lighter textured soil greatly reduced yields in comparison with a soil of heavier texture. Complete commercial fertilizer was applied at a 1,000-pound rate to both the Sassafras sandy loam and the Sassafras loam soils. From other experiments this amount appears to be in excess of the actual quantity required by the crop. It seems, therefore, that the reduced yields on the light sandy loam were primarily due to the poor water relations of this soil, particularly during the period of tuber formation.

[4]LANE, J. H., and EYNON, L. Determination of reducing sugars by means of Fehling's solution with methylene blue as internal indicator. Jour. Soc. Chem. Ind., 42 : 32T. 1923.

TABLE 1.—*Relation of soil texture to yield of artichoke tubers and sugar.*

	Light sandy loam soil	Heavy loam soil
Soil conditions:		
Acidity in 1931, pH	6.02	5.6
Field water content Dec. 6, 1934, %	13.8	22.6
Rainfall : Aug. 15 Oct. 15, 1930-31 av., in.*	3.9	3.9
Acre yields of tubers : 1930-31 av., lbs.	10,292	23,005
Acre yields of sugar : 1930-31 av., lbs.	1,995	4,458

*The normal rainfall for this period, when tuber development occurs, is 8.0 inches.

Wide fluctuations in rainfall occurred in the 5 years for which tuber yields are available. Tuber yields (Table 2) were abnormally low on both soils in 1931 when autumn rainfall was only 41% of normal, but the light sandy loam produced only 7,650 pounds in contrast with 16,244 pounds on the heavy loam soil. Maximum tuber yields were obtained on the light soil in the year of liberal rainfall, whereas on the heavier soil no increase in yields resulted from moisture supplies in excess of 4.5 inches for the period of August 15 to October 15. Since the normal rainfall for that interval is 8.0 inches, it seems probable that maximum yields of tubers may be obtained on soils somewhat lighter in texture than heavy loam. In years of normal autumn rainfall, acre yields of 8 to 10 tons of tubers may be expected on strong sandy loam and light loams in this region when the cultural conditions are similar to those in these tests.

TABLE 2.—*Relation of rainfall conditions to tuber yields of artichokes.*

	1929	1930	1931	1932	1934
			Tuber Yields Per Acre, Lbs.		
Light sandy loam	19,020	12,935	7,650	—	—
Heavy loam	—	29,766	16,244	18,876	25,047
			Percentage Total Sugars in Tubers*		
Light sandy loam	14.6	19.9	18.6	—	—
Heavy loam	—	—	19.3	17.9	—
			Acre Yields of Sugars, Lbs.		
Light sandy loam	2,781	2,570	1,421	—	—
Heavy loam	—	—	2,137	3,384	—
			Total Rainfall, Inches		
Aug. 15–Oct. 15†	8.6	4.5	3.3	7.4	12.8

*Total hexose sugar yielded upon acid hydrolysis of carbohydrates.
†The normal rainfall for this period, during which tuber development occurs, is 8.0 inches.

The acre yields of total sugars did not fluctuate as greatly as tuber yields. Sugar content of the fresh tubers increased in dry seasons and fell in moist years, and thus partly compensated for an opposite trend in total tuber weights. Excluding the most unusual year of 1931, the sugar yields varied from 2,570 pounds to 3,384 pounds per acre on the two soils.

The relation of soil moisture conditions to the moisture content of fresh tubers is shown in Table 3. The heavy loam soil with higher water content produced tubers with a moisture content of 75.3%, while tubers from a light soil contained only 70.6% moisture. The skin of artichoke tubers is poorly protected against moisture losses, and the moisture percentage of the tubers at harvest may represent only the current equilibrium between the soil and plant. However, there is no evidence against the possibility that the moisture content of tubers may have been determined during the period of tuber formation.

TABLE 3.—*Relation of soil conditions to moisture content of artichoke tubers.*

	Heavy loam soil	Light sandy loam soil
Soil moisture content Dec. 6, 1934, %	22.6	13.8
Moisture content of tubers Dec. 10, 1934, %	75.3	70.6
Dry matter in tubers, Dec. 10, 1934, %	24.7	29.4

A large part of the variation in sugar content of tubers in a single season is due to differences in the moisture present. The data from six plats in 1931 similarly treated but varying somewhat in soil texture are given in Table 4. The sugar percentage in fresh tubers varied from 16.13 to 20.25. When sugar percentages of the same tubers are expressed on a uniform moisture content of 75%, the sugar values ranged only from 18.06 to 18.77, within the range of experimental error.

TABLE 4.—*Relation of moisture content of tubers to yields of sugar, 1931 yield test on Sassafras sandy loam.*

Plat No.	Moisture content of tubers %	Total sugar content of fresh tubers %	Total sugar content adjusted to basis of 75% moisture in tubers %
1	78.10	16.13	18.40
13	75.45	18.21	18.54
25	73.00	20.25	18.76
26	76.40	17.72	18.77
38	77.34	16.37	18.06
50	73.50	19.65	18.54

The optimum soil texture for artichokes in this region should be considered from the standpoint both of ease of harvest and of total yields. Although light-textured soils facilitate harvesting, heavier soils give greater certainty as to yields. There is some evidence that heavy-textured soils are less favorable than medium sandy loams in wet seasons. In 1934, with an August-October rainfall of 12.8 inches, the optimum yields were obtained on a medium sandy loam in a field with plants spaced 3 feet by 3 feet. On heavy sandy loam grading into loam in texture, the acre yield was 16,833 pounds. Under identi-

cal treatment the medium sandy loam soil produced 19,499 pounds of tubers and the light sandy loam 18,285 pounds. The water relations of the three soils are indicated by the field moisture contents on December 6, 1934, of 14.9%, 12.1%, and 11.0% for the heavy, medium, and light sandy loam soils, respectively. Although the spacing of plants in the row was wider than optimum for high yields, the influence of soil moisture and aeration on tuber formation is shown by the foregoing results. In general, the commercial production of artichokes would seem most desirable on medium to heavy sandy loams or on silt loams and loams that are in a friable condition.

EFFECT OF LIME AND FERTILIZER ON TUBER YIELDS

The production of artichoke tubers on a light sandy loam receiving 12 types of fertilization, with and without lime, was observed for 3 years (Table 5). The response to lime on this soil was perceptible, even though the pH of untreated soil was 5.9. A 2-ton application of ground oystershell lime prior to planting in 1929 increased the average yield of all plats 5 1% for the following 3 seasons. However, with a 4-8-4 fertilizer, the increase from lime was 16 5%. The change in soil reaction which followed liming was not determined until the close of the third crop year at which time the limed plots showed a reaction of pH 6.1. There was a well-defined inverse relation between

TABLE 5.—*Acre yields of artichoke tubers on light sandy loam in relation to lime and fertilizer treatments, 3-year average, 1929–31.*

Fertilizer ratios*	Acre yield of artichoke tubers, lbs.	
	With lime†	No lime
No fertilizer	10,245	9,758
4-8-4	13,849	11,890
4-12-4	13,261	12,132
4-16-4	13,884	10,735
2-8-4	13,522	11,047
4-8-4	13,849	11,890
6-8-4	14,309	13,082
8-8-4	13,345	13,462
4-8-8	11,678	13,047
6-8-8	12,012	13,509
4-8-2	13,636	12,597
4-8-4	13,849	11,890
4-8-6	11,909	12,729
4-8-8	11,678	13,047
8-8-4	13,345	13,462
8-8-6	13,851	14,018
Ave., 12 treatments	12,958	12,334

*Fertilizer broadcast at 500-lb rate in 1929 and at 1,000-lb. rate in 1930 and 1931. Tuber yields greatly reduced by deficient rainfall in autumn in 1930 and 1931. Average yields for all treatments were 18,511 lbs. in 1929, 12,365 lbs in 1930, and 7,063 lbs. in 1931.

†Ground oystershell lime applied at 2-ton rate prior to planting in 1929 only.

potash and lime for plats receiving more than 4% of K_2O in the fertilizer. From the standpoint of other crops in the rotation, the use of moderate amounts of lime with 4% to 6% of potash in the fertilizer mixture appears preferable to higher potash without lime on the soil used in these tests. However, for 3 seasons, it was possible to compensate for lack of lime by increasing potash in the fertilizer to 8%.

Although the quantity of fertilizer broadcast before planting was increased from 500 pounds per acre in 1929 to 1,000 pounds in 1930 and 1931, no increase in yield was observed from the heavier rate. This may have been the result of limited soil moisture masking the effect of the fertilizer. However, the excellent yields obtained in 1929 suggest that moderate supply of plant nutrients is adequate for artichokes, in contrast with white potatoes which customarily respond to 2,000 pounds of fertilizer per acre in this region. The highest yield on the lime series, obtained with a 6–8–4 fertilizer, was 14,309 pounds, which was 39.8% above plats receiving lime only. For the unlimed series the highest yield, 14,018 pounds, occurred with 8–8–6 fertilizer, 43.7% greater than that recorded on untreated plats.

Increasing the proportion of phosphoric acid above 8% in the fertilizer ratio did not increase tuber yields. Also, very minor differences occurred with changes in nitrogen percentage. Although fertilizers containing 6% nitrogen were superior on limed plats to those with smaller quantities, fertilizer with 8% nitrogen gave the highest yields without lime. Assuming a value of $10.00 per ton for the tubers, 9 cents per pound of nitrogen, and 3.5 cents per pound of phosphoric acid or potash, the most valuable fertilizer analysis was 6–8–4 on the limed series and 8–8–6 on the unlimed plats. With oystershell lime valued at $6.00 per ton, the 8–8–6 fertilizer without lime was the most profitable treatment in this experiment. When grown in rotation with other crops which respond to lime, it is probable that lime plus 6–8–4 fertilizer would be preferable over a period of years.

SUGAR YIELDS AS AFFECTED BY LIME AND FERTILIZERS

The sugar yields shown in Table 6 are considerably below the values which may be expected in normal years as a result of the exceedingly dry autumns of 1930 and 1931 which retarded growth of tubers and storage of carbohydrates. The sugar yields recorded were calculated from total tuber yields and composition of representative samples treated as described in the early part of this report.

Lime increased total sugar yields 6.8% as an average for all 12 types of fertilization, the difference in individual treatments being as great as 30%. On the limed series, high yields of nearly equal value were obtained under 6–8–4 and 4–8–2 fertilizers. On the unlimed series, the 8–8–6 analysis was significantly superior to all others for the 3-year average. In the last 2 of the 3 test years, however, the 6–8–8 fertilizer proved slightly superior to other analyses. In normal years, it seems probable that 6–8–4 fertilizers with lime or 8–8–6 fertilizers without lime would be the most profitable treatments for sugar production on this soil.

TABLE 6.—*Acre yields of total hydrolyzable sugars from artichokes grown on light sandy loam in relation to lime and fertilizer treatment, 3-year average, 1929–31.*

Fertilizer ratios*	Acre yields of total sugars, lbs.	
	With lime†	No lime
No fertilizer	1,771	1,585
4-8-4	2,385	2,029
4-12-4	2,272	2,163
4-16-4	2,345	1,811
2-8-4	2,237	1,849
4-8-4	2,385	2,029
6-8-4	2,406	2,197
8-8-4	2,237	2,142
4-8-8	1,963	2,164
6-8-8	2,057	2,181
4-8-2	2,479	2,170
4-8-4	2,385	2,029
4-8-6	2,129	2,195
4-8-8	1,963	2,164
8-8-4	2,237	2,142
8-8-6	2,319	2,412
Av. 12 treatments	2,217	2,075

*Fertilizer broadcast at 500-lb. rate in 1929 prior to planting and at 1,000-lb. rate in 1930 and 1931. Sugar yields greatly reduced in 1931 by deficient rainfall in autumn. Average yields for all treatments were 2,726 lbs. in 1929, 2,421 lbs. in 1930, and 1,291 lbs. in 1931.

†Ground oystershell lime applied at 2-ton rate prior to planting in 1929 only.

SUMMARY

Tuber yields of Improved White artichokes at New Brunswick, N. J., were greatly affected by soil texture, presumably through the soil moisture relations during the critical period of tuber formation between August 15 and October 15. Loams were distinctly superior to light sandy loams in dry seasons, whereas sandy loams were superior to heavier types in abnormally wet years.

Yields of 8 to 10 tons of artichoke tubers per acre may be anticipated on strong sandy loam soils or loams in fine tilth in normal years, with a maximum of about 15 tons.

The total hexose sugar (largely levulose) content obtained on acid hydrolysis of tubers ranged from 14.6% in a moist year to 19.3% in the driest season. A large part of the fluctuations in sugar content in a single year is due to variations in moisture percentage of the fresh tubers. The moisture content of tubers is higher when the soil moisture capacity is higher and *vice versa*. The extent of normal fluctuation in tuber moisture with changes in soil moisture at specific locations was not determined.

On a light sandy loam having a pH of 5.9 and relatively low organic matter content, lime and 6–8–4 fertilizer increased tuber yields 39.8% over lime alone and 46.6% over untreated plats; and 8–8–6

fertilizer alone increased yields 43.7% above untreated plats. These were the two most profitable fertilizers, assuming the tubers to have a value of $10.00 per ton.

Increasing the amount of fertilizer from 500 pounds to 1,000 pounds per acre did not increase yields in the test period, indicating a much smaller requirement for plant nutrients than for white potatoes.

Total yields of hexose sugars per acre were greatest with lime and 6–8–4 or 4–8–2 fertilizers, or with 8–8–6 fertilizer alone.

Acre yields of hexose sugar ranging from 2,500 to 3,300 pounds are indicated as average yields in normal seasons on suitable soils.

INHERITANCE OF STEM-RUST REACTION IN WHEAT, II[1]

J. ALLEN CLARK AND GLENN S. SMITH[2]

THIS paper presents further studies on the inheritance of stem-rust reactions of wheat. It is one of a series of papers dealing primarily with the near-immune reaction of Hope and H-44 wheats to stem rust, *Puccinia graminis tritici* Eriks. and Henn. This reaction was transferred from emmer, *Triticum dicoccum* Schr., to hard red spring wheat, *T. vulgare* Vill., by McFadden (4)[3] from a Yaroslav emmer x Marquis wheat cross.

PREVIOUS STUDIES

Clark and Ausemus (2) first pointed out that in the F_1 and F_2 generations of crosses with Hope the near immunity of Hope was inherited as a dominant character, whereas resistance, as in Ceres, was inherited as a recessive character. The dominance was imperfect or incomplete. The F_1 plants of Hope crosses with susceptible varieties had only a trace of rust. In the F_2 generation there was a piling up or a preponderance of plants toward the zero or rust-free end of the distribution.

In 1928, at the annual meeting of the American Society of Agronomy, Clark and Ausemus[4] presented F_3 data showing that in Hope crosses with Marquis and Reliance true-breeding, near-immune, resistant, and susceptible strains were obtained, together with four types of segregation. The results were explained genetically on a two-factor basis. In a Hope x Ceres cross only a single-factor difference was shown. These results were in agreement with those obtained by Neatby and Goulden (5) of Canada.

In 1932, Clark and Humphrey (3) showed that the inheritance in the H-44 x Ceres cross is similar to that in the Hope x Marquis and Hope x Reliance crosses previously reported, proving the two-factor inheritance. A good agreement was obtained for a given genetic interpretation in which it was assumed that Hope had a dominant inhibiting factor for near immunity, that Marquis and Reliance had a major dominant factor for susceptibility, that H-44 carried both of these dominant factors, and that the resistant Ceres carried the double recessives.

On the basis of these previous experiments, and those of other workers, Clark (1) has defined the three differently inherited rust reactions.

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[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Also presented at the annual meeting of the Society held in Washington, D. C., November 22, 1934. The inheritance experiments herein reported have been conducted at the Langdon Substation, Langdon, N. Dak., in cooperation with the North Dakota Agricultural Experiment Station, Fargo, N. Dak. A manuscript giving more of the experimental results is on file in the Library of the United States Department of Agriculture. Received for publication February 27, 1935.

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[3]Figures in parenthesis refer to "Literature Cited," p. 407.

[4]CLARK, J. A., and AUSEMUS, E. R. Inheritance of immunity from black stem rust, yield, and protein content in Hope wheat crosses with susceptible and resistant varieties. Washington, D. C., 1928. [Mimeographed, 8 p.]

FURTHER EXPERIMENTS

Apprehension has been felt by some agronomists and pathologists regarding the inheritable power of strains descending from Hope and H-44, in further transmitting the near-immune reaction of emmer. Three strains of the H-44 x Ceres, classified in F_3 as near-immune, were crossed with the susceptible Marquis to determine their power in this respect and the modifying effects of small differences between them. It seemed desirable to determine if additional minor or modifying genetic factors are operating that can be established and distinguished from the uncontrolled variations due to environment.

Further results were obtained on these studies at the Langdon Substation, Langdon, N. Dak., in 1934, under conditions of a fairly heavy natural stem rust infection.

MATERIAL AND METHODS

In the H-44 x Ceres cross there were 24 F_3 strains out of 102 grown which were classified as near immune. This was approximately one-fourth of the population. These were not all assumed to be homozygous but to have the genotypes IIss, IISs, or IISS. Only 1 of the 24 strains was entirely rust free in both the F_2 and F_3 generations. In the F_2 generations the plants varied from 0 to 10% and in the F_3 the strains averaged from 0 to 1.8% rust. Three strains selected from these 24 were crossed with Marquis.

The methods were similar to those previously used and are more fully described by Clark and Humphrey (3) and by Smith and Clark (6). In these crosses no infection was obtained in the F_1 generation at Langdon owing to drought, and only a light infection was obtained on the F_2 plants grown in the greenhouse. Random populations were used for the F_3 studies. The populations from each cross were from only one F_1 plant. The plants were classified according to the amount of stem rust in the frequency classes: 0, 2, 10, 20, 30, 40, 50, etc. These frequencies are 10% class centers with the exception of the first two. The 0 class comprises only those plants having no infection. The 2% class includes those plants upon which a trace of rust was present, resembling the F_1 in earlier crosses.

The breeding behavior of the F_3 strains was determined by (a) the distribution in these frequency classes, (b) the average infection, and (c) the standard deviation. The type of curve is shown by the distribution of the amount of rust on each plant in these original frequencies. The average rust percentage and standard deviation of a single observation, or plant, were computed for each strain to analyze them with respect to their average infection and variability. The standard deviation furnishes a measure of dispersion for determining the homozygous and heterozygous strains.

In this study, summaries ot the rust data for each cross were made by again distributing the average infection of the strains and parent checks into 5% frequency classes, as 0, 1, 5, 10, 15, etc. The smaller rust classes were used here to obtain a finer analysis for the strains themselves than was necessary when classifying the individual plants within each strain. The 1% class includes those strains the average of which falls within 0.1 and 2.4% rust, inclusive. The 5% class includes strains varying from 2.5 to 7.4% rust, inclusive, etc. From this distribution of the strains in each cross, an average rust percentage for each cross has been calculated, together with its standard error, for the purpose of showing the difference in amount of rust of the three crosses.

The standard deviations of the strains in each cross also have been classified into frequencies, and from this distribution an average standard deviation and its standard error were calculated, making it possible to compare the difference in variability of the three crosses. The standard deviation of a single plant also was calculated for each of the parents so as to compare the variability of the strains comprising each cross with that of their parents. Those strains showing the least variability and having the average nearest to that of each parent are, presumably, homozygous and have the same genotype as that parent with respect to rust.

RESULTS

Conditions at the Langdon, N. Dak., Substation usually are favorable for heavy rust infection, especially when seeding is delayed 10 days to 2 weeks later than usual. However, this delayed seeding was unsuccessful for rust development in 1933 because of drought, and no data were obtained that year. In the season of 1934 some of the 1933 rust experiments were repeated from late seeding so as to test the F_3 classification of 1932 for the less variable strains in the H-44 x Ceres cross classified as near-immune, resistant, and susceptible. The F_3 populations of the three further crosses also were grown.

The 24 strains of the H-44 x Ceres cross, classified as nearly immune in 1932, were grown from bulk seed in 1933. As no rust developed, they were reseeded in 1934 from bulk F_4 seed. The classifications for rust of these 24 strains in F_5, 1934, are similar to those in F_3 except that most of the strains were slightly more variable and average slightly higher in amount of rust, the average for all strains increasing from 0.9% to 2.3% of rust. The one parent strain, C-6–1, that had no rust in both the F_2 and F_3 generations had three plants showing a trace of rust in F_5 and averaged 0.2% of rust. The second parent strain, C-6–2, which had a trace of rust in F_2 and averaged 1.8% in F_3, averaged 4.5% in F_5. The third parent strain, C-10–35, which had 10% of rust in F_2 and averaged 1.5% of rust in F_3, had the greatest infection in F_5, averaging 8.0%. With the exception of C-10–35, the 24 strains were found to have been correctly classified in the F_3.

In addition to the 24 strains classified as nearly immune, other strains of the H-44 x Ceres cross, classified as homozygous resistant and susceptible in the F_3 in 1932, were grown as F_5 in 1934. Comparative results of all hybrid strains classified as homozygous for the three reactions showed that they were with the one exception correctly classified in F_3. In F_5, the resistant strains averaged 17.5% and the susceptible strains 35.3% rust. In this experiment, Ceres had 29.7% and Marquis 49.5% of rust. H-44 and Hope had 0.3 and 0.4% of rust, respectively.

Selections from the zero or rust-free class were made from all of the 24 strains for plant-breeding studies, and three of them, or one from each of the strains C-6–1, C-6–2, and C-10–35, were crossed with Marquis for these further genetic studies. The crosses were made in a greenhouse at the Arlington Experiment Farm near Washington, D. C., in the winter of 1932–33, and the F_1 plants were grown at Langdon, N. Dak., in 1933. The F_2 plants were grown in the greenhouse in the winter of 1933–34 and the F_3 populations at Langdon in 1934.

As the three hybrid strains used for further crossing with Marquis have been found to be no more variable than Ceres or Marquis, and as the rust-free selections from these strains used for crossing resemble the bulk seed in amount and variability of rust, it is assumed that the parent plants were homozygous for rust reaction. On this premise they must have either the near-immune (IIss, IISS) or resistant (iiss) genotypes. The strain C-10–35 resembled some of the resistant strains more closely than it did the other near-immune strains, although it had only 8.0% of rust while Ceres had 29.7% of rust.

The distributions and weighted averages of the parents and hybrids for the three crosses are summarized in Table 1 which shows that the F_3 strains of the three crosses averaged 10.22, 21.16, and 39.94% of rust, respectively. In cross No. 1, 27 strains were in the near-immune range, or 0 to 1% rust class frequencies, and only 4 strains in the susceptible range, or 40 to 55% classes. Cross No. 2 had only 4 strains in the near-immune range and 14 in the susceptible range. Cross No. 3 had no strains in the near-immune range and 48 strains in the susceptible range. In the latter two crosses, however, but few of the strains in the susceptible range statistically equalled the Marquis checks in amount of infection. From these average infections alone, it is not possible to make a satisfactory interpretation of the results for the three crosses. The trends are clearly given, however, and the possibility of recovering the reaction of the parents is shown.

TABLE 1.—*Summary of the stem-rust distributions and weighted averages of the three crosses and parents, 1934.*

Stem rust %	Cross No. 1			Cross No. 2			Cross No. 3		
	C-6-1-2	F_3	Marquis	C-6-2-1	F_3	Marquis	C-10-35-1	F_3	Marquis
0	5	1	–	–	—	–	–	—	–
1	1	26	–	2	4	–	–	—	–
5	–	23	–	3	17	–	–	2	–
10	–	21	–	1	10	–	5	2	–
15	–	6	–	–	9	–	1	6	–
20	–	7	–	–	15	–	–	5	–
25	–	4	–	–	11	–	–	2	–
30	–	4	–	–	8	–	–	8	–
35	–	0	–	–	6	–	–	14	–
40	–	2	1	–	6	–	–	6	–
45	–	1	1	–	3	–	–	17	–
50	–	0	2	–	3	1	–	2	–
55	–	1	2	–	1	1	–	9	–
60	–	—	–	–	1	4	–	8	–
65	–	—	–	–	—	–	–	5	5
70	–	—	–	–	—	–	–	1	1
Total	6	96	6	6	94	6	6	87	6
Average	0.01	10.22	49.4	3.66	21.16	57.43	10.99	39.94	66.60

The differences between the crosses are further shown by their average rust percentage means and their standard errors as follows:

Cross	M E	Cross	M E	Cross	M E
1	10.22 ± 1.10	1	10.22 ± 1.10	2	21.16 ± 1.45
2	21.16 ± 1.45	3	39.94 ± 1.69	3	39.94 ± 1.69
Difference	10.94 ± 1.82	–	29.72 ± 2.01	–	18.78 ± 2.22

Since these crosses show such important and significant differences, it seems necessary to assign different genotypic formulas to the parents with respect to their rust reactions.

By using all of the available data on rust, i. e., the original distribution, the average infections, and the standard deviations, it is possible to interpret the results in the broadest sense on a definite genetic basis.

GENETIC INTERPRETATION

In previous studies it has been assumed that a primary factor pair (II) was responsible for near-immunity, which reaction inhibits that of a second factor pair (SS) for susceptibility. Absence of the two dominant factors gives resistance.

The genotypes of Hope and H-44 (near-immune) were postulated as IIss and IISS, respectively, that for Marquis and Reliance (susceptible) as iiSS, and that for Ceres (resistant) as iiss. On this same basis it may be postulated that with respect to the major factors in the present crosses, C-6-1-2 is IIss, C-6-2-1 is IISS, and C-10-35-1 is iiss.

In all cases the phenotype, the genotypic group, and the breeding behavior in the F_3 generation, as indicated by the distribution of the plants of the F_3 strains, are similar to those postulated in the previous paper by Clark and Humphrey (3).

In cross No. 1, C-6-1-2 x Marquis, the segregating and true-breeding strains were separated on the two-factor basis into the seven genotypic groups, previously described, the calculated genotypic ratio being 4 : 2 : 4 : 2 : 1 : 2 : 1. The separation was possible by using the F_3 data on distribution, average infection, and standard deviation. For cross No. 2, C-6-2-1 x Marquis, the F_3 strains were separated clearly on a single-factor basis into three groups. These most nearly resemble groups I, IV, and VII of cross No. 1. For cross No. 3, the F_3 strains could again be separated clearly into three groups, or a single-factor 1 : 2 : 1 segregation. These more nearly resemble groups V, VI, and VII of cross No. 1.

On this basis, the goodness of fit for the three crosses is given in Table 2. A good fit is shown for all three crosses.

For the three crosses, 11,941 plants were classified; for the parent checks, 1,354; and for the F_5 strains and parents, 1,538, making a total of 14,833 plants.

TABLE 2.—*Goodness of fit of the three crosses for stem-rust reaction in the genotypic groups.*

Genotypic group	Cross No. 1		Cross No. 2		Cross No. 3	
	Obtained	Calculated	Obtained	Calculated	Obtained	Calculated
I	27	24	23	23.5	—	—
II	14	12	—	—	—	—
III	26	24	—	—	—	—
IV	8	12	52	47	—	—
V	6	6	—	—	16	21.75
VI	11	12	—	—	46	43.50
VII	4	6	19	23.5	25	21.75
Total	96	96	94	94	87	87
Fit	$P = 0.81$		$P = 0.51$		$P = 0.35$	

OTHER CHARACTERS IN RELATION TO RUST

The segregation of hybrids for characters other than for stem-rust reaction may sometimes have a bearing on the segregation and means of the rust character. In these three crosses, the segregation for awnedness and time of maturity appeared to be the other most important characters involved.

AWNEDNESS

All three of the H-44 x Ceres parent strains, C-6-1-2, C-6-2-1, and C-10-35-1, are awned and Marquis is awnleted. The F_1 plants were strongly awnleted. The random populations in F_3 were classified for awnleted, segregating, and awned strains. The data show a close agreement to a single-genetic factor difference, or a 1 : 2 : 1 ratio, for the awnleted, segregating, and awned strains. For cross No. 1 the obtained numbers were 29 : 39 : 28 and the calculated numbers on the theoretical ratio of 1 : 2 : 1 would be 24 : 48 : 24. This shows a satisfactory agreement ($P = 0.19$). The agreement is closer for cross No. 2 ($P = 0.85$) and the same for cross No. 3 ($P = 0.19$).

In cross No. 1, the awnleted strains averaged lower in rust than the awned, although their percentage difference, 2.98 ± 2.84, is not significant. For the three crosses there was no consistent, important, or significant difference between the awnedness classes and percentage of stem rust.

TIME OF MATURITY

Notes on date of heading and date of maturity were taken on the F_3 strains and parent check rows. The strains headed from July 10 to 20 and matured August 10 to 17. The rows were harvested and classified for rust on the dates of maturity and before the plants had dried. The dates of heading and maturity were very similar and about a month apart. Cross No. 1 was earlier than cross No. 2 by 2.41 ± 0.15 days. There were no significant differences in time of maturity be-

tween cross No. 2 and cross No. 3. Correlation coefficients calculated for date of maturity and percentage of stem rust for the three crosses are $+ 0.283 \pm 0.094$, $- 0.057 \pm 0.103$, and $- 0.252 \pm 0.100$, respectively. For cross No. 1 earliness was positively and significantly correlated with rust reaction, the earlier strain having the least rust. In cross No. 2 there was no relationship, whereas in cross No. 3 there was indicated a negative relation.

DISCUSSION

A similar inheritance for cross No. 1, C-6-1-2 x Marquis (IIss x iiSS), with that of the H-44 x Ceres cross (IISS x iiss) and that of the Hope x Marquis (IIss x iiSS) is shown. This should allay any apprehension regarding the power of strains descending from Hope and H-44 to transmit the near-immune reaction from stem rust. This is the third cross through which it has been transmitted from emmer. The results further support the previously postulated two-factor inheritance with one dominant inhibiting factor for near-immunity and one major dominant factor for susceptibility, with the resistant reaction being recessive to both.

Cross No. 2, C-6-2-1 x Marquis (IISS x iiSS), apparently is principally controlled by the near-immune factor, although the cross shows a greater total range and a larger average standard deviation. The C-6-2-1 parent also carries more rust than H-44, which is assumed to have the same genotype. The small variation shown in the C-6-2-1 check rows and their similarity to the bulk seed of C-6-2 in F_3 and F_5 support the premise that it is a homozygous strain.

Cross No. 3, C-10-35-1 x Marquis (iiss x iiSS), is principally controlled by the one susceptible factor. The strain C-10-35 undoubtedly was incorrectly classified in F_3. While the parent strain C-10-35-1 carries much less rust than Ceres, it is assumed to have the same resistant genotype (iiss). The piling up of the strains toward the susceptible end of the distribution and the lack of any near-immune strains furnish evidence that it is properly classified as resistant. The shortage of resistant strains and the excess of susceptible strains in the single-factor segregation further support the premise that the parent strain was homozygous for the recessives of the two major factors.

Uncontrolled variations due to environment appear to be the principal causes of certain inconsistencies in the interpretation of the results in the three crosses, although there is conflicting evidence indicating that there may be additional minor factors for susceptibility that could account for the differences between Ceres and C-10-35-1 and between certain of the resistant hybrid strains. If these and other small differences are consistently repeated from season to season or from place to place, there will be strong circumstantial evidence of additional genetic factors. No additional genetic factors, however, can be directly established from the results of these crosses. From further study of a cross between C-10-35-1 and Ceres, it might be possible to establish an additional minor factor for susceptibility. There is no evidence, however, of an additional minor factor or factors for near-immunity.

SUMMARY

The inheritance of the three stem-rust reactions—near-immunity, resistance, and susceptibility—has been further studied in hybrids. Earlier crosses were interpreted as showing that Hope has a single dominant inhibiting factor for near-immunity, that Marquis and Reliance have a major dominant factor for susceptibility, that H-44 carries both of these dominant factors, and that the resistant Ceres carries the double recessives.

Three further crosses are interpreted as showing that the same major factors principally control the inheritance. No additional minor or modifying factors could be directly established from the results of these crosses. Certain variations and inconsistencies in the interpretation are considered about as likely due to variations caused by environment as to additional minor or modifying genetic factors. The rust genotype of strain C-6–1–2 is postulated as IIss, similar to Hope; strain C-6–2–1 as IISS, similar to H-44; and strain C-10–35–1 as iiss, similar to Ceres. The rust reactions in cross No. 1, C-6–1–2 x Marquis (IIss x iiSS), are controlled by the interaction of two major genetic factor pairs, the near-immune factor inhibiting the susceptible factor. Cross No. 2, C-6–2–1 x Marquis (IISS x iiSS), is principally controlled by the one near-immune factor pair and cross No. 3, C-10–35–1 x Marquis (iiss x iiSS), by the one susceptible factor pair.

These further studies confirm the results from the earlier crosses on the inheritance of stem-rust reactions in wheat.

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EFFECT OF FERTILIZERS ON THE LENGTH OF COTTON FIBER[1]

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PREVIOUS work at the Texas Agricultural Experiment Station has shown that application of complete fertilizers to cotton on Kirvin fine sandy loam and Lufkin fine sandy loam, both of which respond to applications of phosphoric acid, had no appreciable effect on the length of fiber.[3] In a few instances, however, applications of phosphoric acid on the Kirvin fine sandy loam soil produced increases in the length of fiber, which, although statistically significant, were not large enough to be detected consistently in the commercial classing of cotton.

It was thought desirable to make additional studies on other soils low in phosphoric acid to determine whether fertilizers have any effect on length of fiber. Accordingly, studies were made on Lake Charles clay at Texas Substation No. 3, Angleton, on which cotton responds readily to applications of phosphoric acid. The work was conducted in 1932 and 1933, but the test in 1932 was destroyed by a tropical hurricane on August 13, thus results are available for 1933 only.

METHODS

The work was done with cotton in a 3-year rotation of cotton, cotton, and corn. The following fertilizer treatments applied under the cotton before planting were used: At the rate of 400 pounds per acre, 0-4-0, 0-8-0, 4-0-4, 4-12-4; 0-12-4, 8-12-4; and 4-12-0; and at the rate of 800 pounds per acre, 4-12-4, 8-12-4, and 8-12-8.

After the cotton had emerged to a good stand and had reached a height of about 4 inches, it was thinned to one plant every 12 inches in the row, previous work having shown this to be a satisfactory spacing for the region. When the cotton began to bloom actively, about 250 blooms were tagged on each plat on the same day. The bolls resulting from these tagged blooms developed under the same weather conditions. When the bolls had matured and opened they were cut from the plant, the bolls from each plat being placed in a separate bag. The number of bolls harvested ranged from 43 to 85 for each plat.

The length of lint was obtained by combing the fiber on the second pair of seeds of a normal lock from every boll harvested. The combed lint was removed from the seed, placed on a black velvet board, and measured to the nearest millimeter. A statistical analysis of these data was made by Fisher's method[4] of comparing two means.

[1]Contribution from the Division of Agronomy, Texas Agricultural Experiment Station, College Station, Texas. Technical Paper No. 316. Received for publication March 4, 1935.

[2]Chief in Agronomy and Superintendent of Texas Substation No. 3, respectively.

[3]REYNOLDS, E. B., and KILLOUGH, D. T. The effect of fertilizers and rainfall on the length of cotton fiber. Jour. Amer. Soc. Agron., 25 : 756–764. 1933.

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EXPERIMENTAL DATA

The work was planned so as to have four replications of each treatment. Due to an error in the field, however, data were obtained on only three plats which received 400 pounds per acre of the 4–12–4 fertilizer (used as soil checks) and on one plat each of the other treatments. The length of the fiber from each of the three check plats was compared with that from the other two check plats and the results of the other treatments were compared with the results of the nearest check plat.

A comparison of the results of the three check plats (M–25, M–30, and N–25), which received the 4–12–4 fertilizer at the rate of 400 pounds per acre, shows that there was practically as much difference in length of fiber between these plats as there was between any of the treatments. The fiber on check plats M–30 and N–25 was significantly longer than the fiber from check plat M–25, as shown in Table 1. Plat M–30 produced fiber 26.64 mm long, which was 1.18 ± .32 mm longer than the fiber from plat M–25. This difference is highly significant, with P .0002, which means that a difference as great as this would occur only about twice in 10,000 times due to chance alone. Further, plat N–25 yielded fiber 26.56 mm long, which was 1.10 ± .26 mm longer than the fiber from plat M–25. This difference also is highly significant. These differences in length of fiber on three uniformly treated plats indicate that something other than the fertilizer treatment caused these differences in length of fiber.

The length of fiber from the plats treated with 800 pounds of 4–12–4, 8–12–8, and 8–12–4 were compared with the length of fiber from plat M–25, the nearest check plat. The plat which received the 4–12–4 fertilizer at 800 pounds per acre produced fiber 26.49 mm long, or 1.03 ± .26 mm longer than that from plat M–25 (Table 1). This wide difference is highly significant. The plat which received the 8–12–8 fertilizer also yielded fiber significantly longer than plat M–25.

Of the five comparisons with check plat M–30, only two significant differences in length of fiber were obtained (Table 1). Plat M–30, which received the 4–12–4 fertilizer at 400 pounds per acre, produced fiber significantly longer than the fiber from plats treated with the 0–12–4 and 8–12–4 fertilizers.

The other check plat, N–25, yielded fiber that was significantly longer than the fiber from the unfertilized soil or from the 4–12–0 treatment (Table 1).

DISCUSSION OF RESULTS

Of the 13 comparisons on length of fiber given in Table 1, six differences are highly significant and two others significant, considering P .05 (odds 19 : 1) as significant. The mean difference in length of fiber in the other comparisons was not significant. The greatest absolute difference in length, 1.38 mm, was found in the fiber from the plats treated with the 4–12–4 fertilizer at 400 pounds per acre and the 8–12–4 fertilizer at 800 pounds per acre. This difference is highly significant for the probability is that a difference as great or greater than this would not occur once in 10,000 times due to chance alone.

TABLE 1 —*Statistical significance of mean difference in length of cotton fiber from plats receiving different fertilizer treatments*

Comparison of treatments	Length of fiber, mm	P
	Comparison of Check Plats	
4-12-4 (M-30) 4-12-4 (M-25)	26.64 ± .27* 25.46 ± .18	— —
Difference	1.18 ± .32	.0002
4-12-4 (N-25) 4-12-4 (M-25)	26.56 ± .18 25.46 ± .18	— —
Difference	1.10 ± .26	< .0001
4-12-4 (M-30) 4-12-4 (N-25)	26.64 ± .27 26.56 ± .18	— —
Difference	.08 ± .32	.8026
	Comparisons with Check Plat M-25	
4-12-4 (800 lbs.) 4-12-4 (M-25)	26.49 ± .19 25.46 ± .18	— —
Difference	1.03 ± .26	< .0001
8-12-8 (800 lbs.) 4-12-4 (M-25)	26.06 ± .22 25.46 ± .18	— —
Difference	.60 ± .28	.0324
4-12-4 (M-25) 8-12-4 (800 lbs.)	25.46 ± .18 25.26 ± .17	— —
Difference	.20 ± .25	.4238
	Comparisons with Check Plat M-30	
4-12-4 (M-30) 0-12-4	26.64 ± .27 25.76 ± .17	— —
Difference	.88 ± .31	.0046
4-12-4 (M-30) 8-12-4	26.64 ± .27 25.32 ± .19	— —
Difference	1.32 ± .32	< .0001
4-12-4 (M-30) 0-4-0	26.64 ± .27 26.46 ± .21	— —
Difference	.18 ± .34	.5962
4-12-4 (M-30) 0-8-0	26.64 ± .27 26.12 ± .20	— —
Difference	.52 ± .33	.1142
4-12-4 (M-30) 4-0-4	26.64 ± .27 26.13 ± .25	— —
Difference	.51 ± .37	.1676

*The standard error and not the probable error is used here

TABLE I.—*Concluded.*

Comparison of treatments	Length of fiber, mm	P
	Comparisons with Check Plat N-25	
4-12-4 (N-25)	26.56 ± .18*	—
4-12-0	25.73 ± .24	—
Difference	.83 ± .30	.0056
4-12-4 (N-25)	26.56 ± .18	—
No fertilizer	25.65 ± .20	—
Difference	.91 ± .27	.0008

*The standard error and not the probable error is used here.

As shown above, there were some significant differences in the length of fiber between several of the fertilizer treatments. These differences, however, do not seem to be related in any way to the amounts of nitrogen, phosphoric acid, or potash, or to the total amount of fertilizer. Since there was practically as much difference in length of fiber between the three uniformly treated check plats as there was between any of the fertilizer treatments and since there was no consistent relation between the amounts of nitrogen, phosphoric acid, or potash, or amounts of fertilizer, and the length of fiber, it seems reasonable to conclude that the differences in length of fiber were due to something other than fertilizer treatments.

SUMMARY

In previous work to determine the effect of fertilizers on length of fiber, the application of phosphoric acid to cotton on a soil that responds readily to phosphoric acid apparently increased the length of fiber. An experiment using 10 different fertilizers was conducted in 1933 on Lake Charles clay soil, which is low in phosphoric acid, to study the matter further. Some significant differences in length of fiber were obtained from the variously treated plats, but the differences apparently were not caused by differences in the amounts of nitrogen, phosphoric acid, or potash, or to different rates of application of the fertilizer.

AGRONOMIC AFFAIRS

KORSMO'S WEED PLATES

PROFESSOR Emil Korsmo of Oslo, Norway, the recognized authority on weeds in Europe, has now made his 30 colored weed plates available. These plates are from paintings that were made in Korsmo's own laboratory. They are life size and are 84 x 64 cms and show the plants from seed to full development. The scientific name is given in all cases as well as the most common name used in England, Germany, France, and Norway. A booklet describing the entire set comes with the set of plates. The charts come in two forms, on sheet form paper and on leather paper with cloth edges and eyelets. The price of the former is RM 22 and the latter RM 38, with a duty of 25%. The leather paper with the eyelets for convenient hanging is to be recommended. They may be gotten through Koehler and Volckmar A.-G. and Co., Leipzig, Germany.—A. L. BAKKE, *Iowa State College, Ames, Iowa.*

NEWS ITEMS

THE ANNUAL summer meeting of southern agronomists will be resumed this year. The 1935 meeting will be held in Virginia sometime in August. The exact dates and an itinerary will be announced in the July issue of the JOURNAL.

President H. K. Hayes has received a communication from Dr. Franco Angelini announcing the sixth General Assembly of the International Federation of Technical Agriculturists to be held in Brussels on July 31. Also in Brussels, on July 26 and 27, will be held the first International Congress of the Agricultural Press; and on July 30, the fourth annual International Conference of Agricultural Teaching.

ACCORDING to *Science*, Dr. C R. Ball has been named Executive Secretary of the Advisory Council for the federal government in the project to develop the economic and social resources of the Tennessee Valley. Apart from power generation and distribution, the Tennessee Valley project embraces rural rehabilitation and ranges from erosion control to wild life preservation.

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THE INTERDEPENDENCE OF AGRONOMIC RESEARCH AND RESIDENT AND EXTENSION TEACHING[1]

J. S. OWENS[2]

THE early history of our agricultural colleges is the story of the achievements of a few men. They were men of ability, usually well trained in science. While it may be true that their success was due in part to the contributions which science could make in its virgin applications to agriculture, it is worth while looking for other factors The early leaders started with problems which were closely associated with agricultural practice. They knew them first hand; they often performed every operation in their own investigations; they were in frequent association with farmers and usually with classroom students as well. Only a little time was required for keeping abreast with the investigations being conducted by other workers. The problems which have arisen with expansion of organizations and higher specialization could not have existed. Each worker could develop his own work; he bore the responsibility for it; he was unencumbered with the *impedimenta* which now result from many regulations and the difficulties of correlating relationships between several closely related fields of knowledge.

The only discussions of these problems which have been found are those reported in the recent *Proceedings* of the annual meetings of the Land-Grant College Association. They have been confined almost exclusively to problems of administration and have ignored completely the one factor which seems to be reaching an end point in teaching an applied science; the continuation of a scholastic attitude and a comprehensive acquaintance with the rapidly developing information. The explanation may be that only administrators have been sufficiently interested to attempt making a contribution. However, they have been interested in functioning machinery. The problems incident to broadening knowledge and specialized duties need examination by those who are closest associated with them. They are in the best position to determine the real worth of their endeavors.

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[1]Contribution from the Department of Agronomy, Connecticut State College, Storrs, Conn. Also presented before the Northeastern Section of the American Society of Agronomy in joint session with Section O, A. A. A. S., and the Potato Association of America, December 29, 1934, Pittsburgh, Pa. Received for publication May 4, 1935.

[2]Professor of Agronomy.

The agronomy field is a particularly suitable one for studying recent trends in administration, and in functional separation and their ultimate consequences. The field has been growing. Occasionally, some group comprised mainly of investigators feels their problems so vital and different that they wish to "separate," and form a new organization because they believe they have developed a *new science*. Contributions, particularly in soils, concern all plant production and not farm crops alone. Likewise, plant and chemical developments, outside the narrower field of agronomy are seemingly increasing at a geometrical ratio and they may mean more to farm crop production than those made by the more strictly farm crop research. The extension teacher sees farm situations becoming more intricate constantly. The fund of information has become so vast that even the light of twilight has passed for the extension specialist who attempts to keep abreast of the information which has agronomic relationships.

It will be assumed for this discussion that extension is education and not promotion to effect the perpetual existence of an organization. While this assumption may have been widely accepted the difficulties involved in its continuation have received scant attention. If the goal is superficial work of temporary value, we need only page the advertising expert.

Much research has necessarily become more and more remote from its practical, or at least from its direct and immediate, use. The simple, almost obvious, comparisons and confirmations have, in the main, been completed. Research requires highly developed technic and special skills. Limitation of time alone makes close observation of farm problems difficult. Sometimes, too, the research worker does not possess the personal qualifications necessary for interpreting and popularizing his own discoveries. Research and teaching tend to separate. They continue growing further apart.

Through its many contacts, extension has developed into an advertising agent for the entire institution. Since it is becoming more remote from the masses, research is becoming more dependent upon extension for creating support. On the other hand, because extension demands comprehensive training and experience, it continues drawing upon research staffs for personnel.

What are some of the possibilities for meeting the problems which have been suggested? Suppose we consider starting with the specific problem to be solved and adjusting plans to it. This is what the earlier workers did. Does the problem originate from a real need? Will it involve laboratory, field plat, or farm studies? What person or persons are most capable for conducting the experiments? If the problem is a large one, will the one who is most familiar with the problem have an opportunity to explain its meaning to the farmers of the state?

The following seems a more common procedure. A member of the research staff, others have little or no opportunity, feels that he must undertake a new project. It may be his pet hobby or something which would appear to make a good showing. This is not meant to suggest that only problems which have visible economic value should be undertaken.

After valuable, and sometimes not valuable, conclusions are reached, bulletins intended for professional colleagues are written. The extension worker may not see "practical" use, or what is more probable, he is so busy with many little things that he passes over the matter entirely. Even if the problem seems important to the extension program, the specialist cannot have the same understanding and enthusiasm about its meaning as the one who did the work.

The illustration just given was meant to suggest division upon a problem basis instead of upon a method or "job" basis. There are difficulties involved, but its use is worth more consideration. How could it be worked out? Assume that pasture production is of great importance in a state and that there are many serious problems associated with it. One man might, with some assistance, conduct the research at the college, outlying fields or substations, supervise demonstrations, write popular as well as technical interpretations, and lead the whole teaching program in resident and extension.

Such a plan probably would mean reorganization of our institutions, but present divisions are not sacrosanct; they are the result of laws made before experience was secured and before the problems became so intricate. The real difference is in the importance of the machinery and the product which the machine should be designed to produce.

It may seem idle to suggest closer relationship between workers with present organizations. Yet some institutions are broken up, extension specialists are some distance from the others and, in some instances, research headquarters are away from the college campus. Formal conferences may be necessary with larger staffs, but they cannot replace frequent informal contacts.

Administrators are obligated to help in creating a spirit for cooperation by removing causes for petty jealousies and in securing freedom from unnecessary regulations and interference.

It is conceivable that more interchange of duties could be developed. Extension programs might be interrupted slightly, but the work become more effective in the end. The extension worker might teach a course occasionally or conduct certain investigations. The interchanging would be refreshing, give more opportunity for study, and develop a mutual appreciation of the difficulties in the other types of work. Incidentally, it might help in keeping all divisions on an equal basis.

Under any organization, the leader in one division cannot dictate the procedure for the leader in any other. The extension worker, for instance, should know more about his problems than his research associate and *vice versa*. Yet, the research worker should know the extension problem and be given opportunity to analyze and to offer criticisms.

Little attempt has been made to answer the problems raised. Any which are adequate would seem to be based upon the following questions: With the increasing fund of agronomic knowledge and growing complexity of problems, can the teacher, more particularly the extension teacher, continue covering large portions of the field, or as is often the case, the entire field of agronomy? Can research afford

to become further and further removed from the source of the problems which are the occasion for its existence? Is any division of work which does not offer opportunity and stimulation for a continued high plane of scholarship satisfactory for any particular type of the work and consequently for all?

HELPS TO EXTENSION WORKERS IN DETERMINING THE NEEDS OF SOILS AND CROPS[1]

Ernest Van Alstine[2]

WHAT is stated here on the subject of chemical soil tests is from the viewpoint of one who is interested more particularly in the production of dairy crops and general farm crops rather than in market gardens or greenhouse crops.

If it is the purpose of this paper to "start something", it is hoped that it might be a fuller realization of the pressure under which most agricultural extension workers and especially the county agricultural agents work and their impatience to get on with committee meetings, correspondence, circular letter releases, news articles, farmers' meetings, demonstrations, program making, membership drives, reports, exhibits, keeping up on the newest information along all lines of agriculture, and innumerable other things of which these are only a suggestion, all of them, however, important and necessary to the continuation of their jobs and the good they hope to accomplish.

It is hoped that it might be possible to start some accurate thinking along the line of the difficulties in the way of the county agent giving careful persistent study to such intricate problems as that of soil chemistry. It is also desired to direct attention to those sources of information available to county agents for which they may not be receiving full credit.

The problem of the experimenter in soil fertility is not quite that of the agricultural extension agent or the extention specialist. The research worker studying soil fertility problems wants to know what plant nutrient is deficient or which one or more plant nutrients will give crop responses when used on a particular soil under definite, known conditions and for a particular crop. From this point he may generalize, or perhaps he may set up another experiment.

The extension worker on the other hand, wants to know what answer to make to each of 50 to 500 or more farmers who are asking what kind and amount of fertilizer will give satisfactory results for a variety of crops when used on one to a dozen fields varying in soil types and differing in their past lime and fertilizer treatments. If the handicaps to the "extensioner" could stop here the problem would not be so difficult, but he must be able to give his answer for the unknown moisture and temperature conditions of the coming season with no assurance of the cultural care that will be given the crop and no very accurate guide as to the value of the crop after it has been grown. Moreover, the answers must be given between the spring thaw and crop planting time, in many instances between spring plowing time and seeding. This is also the time of year when

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[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Also read before the Northeastern Section of the American Society of Agronomy at Pittsburgh, Pa., December 29, 1934, in joint session with Section O, A. A. A. S., and the Potato Association of America. Received for publication February 15, 1935.

[2]Extension Professor.

there are a thousand and one other things for both the county agent and the extension specialist to be doing.

The answer for each field must be right, not only in a majority of cases or in 75 or 80% of the cases, but if a county agent is to keep the loyal support of his farmers he must be right in close to 100% of the cases. He should not be expected to answer everything, but he should be right in the answers that he does make. Certainly when he tells one of his farm bureau committeemen or a county supervisor that he should buy a particular kind of fertilizer to get good results with a certain crop, he must be sure that this particular case is not one of the 20% that fails while a neighbor gets as good or better results without advice of the county agent and at less expense.

Let us look at some of the difficulties that face a county agent in his attempt to use a chemical soil test. In the first place, it is recommended by those who have made most use of chemical soil tests that in order correctly to diagnose the need for any one element of plant nutrients, some knowledge is necessary as to the sufficiency or overabundance of each of the other 9 to 14 things for which chemical tests have been devised and advocated. Some of this information is available for most soils without making tests, such, for instance, as the absence of sodium and chlorine in harmful amounts on well-drained soils, but there still remain to be made more tests than any county agent can make. He does not have the time for it and few county agents are properly trained for making such tests. He does not know how to go about the work nor how to take the precautions necessary in making reliable tests. Not only does he lack the training, but he also lacks the incentive, the desire, and the opportunity to acquire the necessary information without falling farther behind in some of the things that to him seem to give greater promise of valuable returns for the time and effort expended.

In the second place, few farm bureau offices are equipped or can be equipped to do chemical work. Such testing equipment as is in use for determining lime requirement is often cared for and handled in such a way that a chemist would wonder how reliable results could be secured. Office clerks are frequently called upon to make the lime requirement tests.

In the third place, with 10 chemists testing a single soil the results would probably agree *fairly well*, provided they all used the same methods. If they were all agronomists as well as chemists, we wonder how many different recommendations there would be for the same crop. With tests by 40 or 50 different county agents or their assistants, how many different kinds of recommendations might be expected?

The average county agent is not a chemist and he is not going to be one regardless of our wishes in the matter. Not only that, but altogether too many of them lack the scientific information regarding soil fertility and soil chemical activity which is essential for them to be able to make recommendations on the basis of chemical tests.

In order to make such interpretations we find in the literature on soil testing, and we fully agree with it, that careful consideration must be given to the following:

1. The nature of the crop to be grown.
2. Root penetration and extent, whether as a result of plant habit of growth or as a result of physical soil condition, ground water level, or something else.
3. Climatic conditions, including temperature, humidity, and water supply.
4. The deficiency or overabundance of other plant nutrients and plant toxins.
5. Any and all other factors limiting plant growth.
6. Physiological problems influencing plant growth such as the substitution of sodium for potassium, the utilization of ammonnium in place of nitrate nitrogen and others.

If a skilled, scientifically trained chemist-agronomist, or agronomist-chemist, after due consideration of all necessary factors which may influence the drawing of proper conclusions, is able to hit the nail squarely on the head in only 80% of the cases and thinks he is doing very well indeed if he misses only 1 out of 10, what is to be expected of an overworked (or overharassed if you prefer) county agricultural agent who is entirely untrained, unskilled, and unpracticed in that sort of thing? Experience leads us to believe that he will either play with the tests for a time until he learns how time-consuming and difficult of proper interpretation the whole thing is and then give it up entirely, or he will continue to test soils and make recommendations merely on the basis of the test alone, never realizing the limitations of the tests nor knowing how many times his recommendations are no better than the farmer's guess.

As an illustration of what is meant, mention might be made of some tests for determining lime needs of a soil for alfalfa. Apparently some workers are able to distinguish differences as low as 500 pounds of limestone to the acre in the needs of the plowed soils and make recommendations accordingly. This is probably well within the limit of error in evaluating the influence of other factors upon the effectiveness of any reasonable amounts of lime that may be used.

It may be suggested that the extension specialist should make the interpretations of the results secured by the county agent, but it is difficult enough to interpret one's own results without attempting those of some one else, and the writer for one should not want to try it.

It is very difficult if not impossible for any specialist to get the information necessary to go with chemical tests for interpretation and recommendation on soils sent to him or soils collected by himself. It might be possible for an agent to get this information and the soil samples and forward both to some one qualified to make tests and recommendations. Such a person would certainly be busy trying to get recommendations back to the county agents of a state like New York, Pennsylvania, or even the smaller states. We wonder, too, if in any event, he would be earning his money if he got many samples taken merely for the sake of impressing farm bureau members with the state service available to them. There would be plenty of samples taken for no other purpose even as there now are when agents do their own testing and for lime requirement only.

Over against these handicaps of the county agent in making and interpreting chemical soil tests there are many guides which the agent may see and follow to a high percentage of accurate recommendations, guides which a good man but one who is not spending his life and effort in that particular county cannot even see. A county agent has the possibility of the following helps in formulating a fertilizer recommendation:

1. A knowledge of farmers' results with different fertilizers on similar soils and for the crops in question.
2. The advantage of any field experiments on the same or similar soils in the county or state.
3. Direct information from the farmer he hopes to serve about treatments and responses on the field in question.
4. An opportunity to study the field and the soil in place.
5. The possibility of gaining some information about the farmer's practices, his weed problems, and his financial condition,

It is seldom that a county agent is not able after a few years of service to say that the soils in this locality must be limed for alfalfa or for clover, or that the soils in that section respond to superphosphate more than to anything else, or that potash is needed here.

It is true that he should have all these advantages when attempting to interpret chemical soil tests, but I think you will agree that his object is to get the information necessary to a proper recommendation. If he can make such a recommendation from the kind of information he has or knows how to get easily, information he is well fitted to interpret, it may not be so important that he go much farther.

It may be observed that in the development of the various soil tests comparison is made of one method with another, and the best criterion for reliability of a test is the degree of agreement secured with field results where yield records have been kept. Where field records are available or where response to liming and fertilizing can be observed on fields and farms for which information is wanted it is most desirable, and chemical tests that do not agree with such field observations are properly discarded.

This is not to say that the tests should be done away with or that they are unnecessary and of no value, even though a reading of the literature on soil testing gives one the impression that there has been considerable analytical target practice to see who could come closest to the mark set up by field results and quite a number of shots go wide of the mark. The literature reveals, too, a wide difference of opinion as to who is the best marksman or whose system shoots best.

The tests are valuable and should be used when and where they can be properly made and interpreted by some one who knows their limitations and their significance. The writer knows of no better way to locate the probable reason why some soils do not respond to any of the generally recommended treatments. Had a certain city made use of some of these tests in advance, it might have saved considerable expense when it was found after spending a great deal of money and effort on a park system that the soil was so impregnated with salt that nothing would grow on it.

If these soil tests are made by some one who can devote enough of his time to the work so that results may be considered reliable, and if with their help a study can be made of soil types, or of soils having similar properties, and if this information of general application for particular soils can be made available to county agents in empirical but usable form and to the extension specialists in a way to make more intelligible to them observed responses or lack of responses to soil treatments, then they will serve a very useful purpose. The cooperative effort of an extension specialist in crops and a soil analyst would result in much good. It is difficult, if not impossible, for one man to perform the functions of both. Probably the wholesale use of soil analyses made yearly or separately on the same fields as would be requested by farmers who think they can get from a test tube the answer to their fertilizer problems would be not only unnecessary but unwise.

What is needed among the field men is a fertilizer program for the important soil types of a state, a fertilizer program arrived at by preliminary soil analyses, by field tests with different fertilizing and cropping methods, by out-of-door cropping tests in frames, or by greenhouse culture tests with the various soils. Fertilizers and lime need to be tried on the different kinds of soils to learn their greatest needs. If we then have the past record of a particular field for the soil of which we have this information, it should be possible to advise a lime and fertilizing program that will be accurate for a rotation or for a period of years. Whether a man should lime this year or wait until next may not and often does not depend so much upon the condition of the soil as revealed by a chemical test as it does upon the farmer's financial condition. That is especially true for such conditions observed a number of times when county agents, and good agents too, have told farmers that they could not grow alfalfa without first liming (advice given presumably so as to be on the safe side), and yet in spite of a lack of the lime because of inability to pay for it, the seedings were made with excellent results.

If a soil needs phosphorus this year it will probably need it next. At least it should be applied in amounts as great as those removed in crops.

Training schools for extension field men are needed to teach them to interpret observations that may be made on the soil without a chemical analysis. They need instruction in making observations so they may be able to see what should be, but often is not, plainly evident. More thorough training in certain phases of soil physics, in the principals of soil chemistry and in soil mapping or the basis for soil type classification is needed. A little more of the geology of soils and of soil biology and the influences these factors have upon plant growth and crop production is also needed.

When county agents are well grounded in these fundamentals, they will be better able to give good advice on soil fertility problems and will be less likely to misinterpret chemical tests when they are properly made by some one who knows how to make them.

A COORDINATED PROGRAM FOR RESEARCH AND EXTENSION[1]

C. H. MYERS[2]

THE committee responsible for the formulation of this program was influenced, according to a statement by the secretary, by "considerable criticism both from members and from non-members of the Northeastern Section of the American Society of Agronomy pertaining to the lack of agreement and cooperation between the research and teaching agronomists and the extension agronomists."

Those invited to discuss the problem were advised by the committee to speak frankly to the end that constructive thought and action might be stimulated. It is in accordance with this spirit and attitude that the writer has accepted the opportunity to present the problem as viewed by one engaged in research and teaching.

At the very outset it is fair to accept the premise that the relationships between those engaged in research and extension are not all that they should be, in spite of the very significant contributions that have been made in both lines of endeavor to the improvement of agriculture. Particularly striking is the summary by Warburton[3] of accomplishments in extension during the decade 1914-1924, the period beginning with the inauguration of the Smith-Lever Act. The summary of the next decade ending with the current year will undoubtedly be even more impressive. In the face of this, one hesitates to criticise, but it must be remembered that progress is best made as the result of constructive criticism. With this axiom in mind and with a background of some 25 years of experience, the early part of which was in the rôle of an extension man, the writer dares to point to certain phases of the relationship between research and extension in which he sincerely believes improvement can be made.

Perhaps the discussion should be bounded by an attempt to define research and extension. Sometimes these two fields of effort are so closely integrated that it is difficult to tell where one leaves off and the other begins, although for administrative purposes the line of cleavage is sometimes clearly though not always logically drawn. Some years ago Dr. E. W. Allen[4] furnished a definition of research as compared to extension which seems helpful in this connection. His definition, which was included in a special report made for and to the New York State College of Agriculture, was as follows:

"Research is here used in a generic sense to include the various types and grades of effort for advancing knowledge, securing and verifying information, testing its application, and reducing it to

[1]Paper No. 210, Department of Plant Breeding, Cornell University, Ithaca, N. Y. Paper also read before the Northeastern Section of the American Society of Agronomy in joint session with Section O, A. A. A. S., and the Potato Association of America, December 29, 1934, Pittsburgh, Pa. Received for publication January 26, 1935.

[2]Professor of Plant Breeding.

[3]WARBURTON, C. W. Ten years of cooperative extension work under the Smith-Lever Act. U. S. D. A. Mimeograph 1596. May 8, 1924.

[4]ALLEN, E. W. Research in the State Institutions under Cornell University. Mimeograph Report. 1928.

practice under varied conditions—these and similar activities where the effort is still in the acquisitive or experimental stage, as distinguished from that of teaching or aiding persons to make application to their own conditions."

In defining research, Dr. Allen has also defined extension and in a way which shows clearly how these two fields are related and integrated with each other. Research furnishes the basis for all teaching and extension. It must always precede and keep ahead. Truth must be established before it can be extended or applied. Demands of extension can stimulate and aid in research, but extension can not or should not build higher than its foundation justifies. Disregard of this fundamental relationship is logically bound to result in a situation meriting criticism.

Granting that the relationship between extension and research as stated above is correct, it is worth our while to examine the organized development of these two fields of endeavor to see whether or not the proper balance has been maintained. Of course, each of these had their beginning in the far distant past. No one can set an arbitrary date for the first piece of research or the date when it was first applied to life problems. It is fair to presume that the Neanderthal man or even his predecessor, the Peking man, must have done research and extension of a sort, in accordance with Dr. Allen's definition. As a further illustration, we may cite the field of genetics, the newest member of the biological sciences. It is not infrequently stated that the science of genetics had its beginning about 1900 with the rediscovery of Mendel's principles of heredity. As a matter of fact, the roots of this science go back much further, and Mendel had many predecessors who made important discoveries upon which he was able to build. It remained for him to provide a method of attack by means of which he was able to interpret his own findings as well as the findings of others. Other fields of research have been built up in a similar manner. Along with discoveries of new truths, applications have been made. Indeed, many times application was made before the discovery of truth. Much plant and animal breeding was done before the science of genetics was established. Here extension may be said to have preceded research and as a result sometimes worked ineffectively, as for example in the attempt to get pure breeding stock of the Andalusian fowl, roan cattle, and the commercial carnation.

Organization of research on a comprehensive scale had its beginning in the United States in 1862 with the passage of the land-grant act for establishment of agricultural colleges. The funds provided by this act, supplemented by those provided through the passage of other acts such as the Hatch and Adams, together with appropriations by the individual states, have resulted in the establishment of agricultural research on a broad and firm basis in the United States. Some 60 years later, the Office of Experiment Stations[5] reported expenditures for the year 1924 as follows:

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[5]Office of Experiment Stations. Work and Expenditures of the Agricultural Experiment Stations. 1924.

Funds administered by Office of Experiment Stations	$ 1,743,600
Funds in addition to above	8,594,074
Total	$10,337,674

The above figures do not include expenditures made by private research institutions not affiliated with the agricultural colleges or experiment stations. The year 1924 was chosen because it marked the end of the first 10-year period of organized extension in the United States. The more than 10 million dollars which was spent for organized research in the United States in the year 1924 seems a sizable sum and it would be superfluous to point out to a group of agronomists the great contributions made since 1862 to the improvement of agriculture. Suffice it to say that they are many in number and that their monetary value to the nation has been immeasurably greater than their cost.

For comparison let us now briefly trace the development of organized extension. This really had its beginning in the demonstration work started in the South by Dr. Seaman A. Knapp in 1904. In 1909, President Theodore Roosevelt's Country Life Commission rendered its report. This gave an impetus to the movement for an organized program of extension which finally culminated in the passage of the Smith-Lever Bill in 1914, the first of a series of acts to promote extension, some 60 years after organized research had been established. That it seems to be catching up pretty well with its foundation source is evidenced by the following items taken from the report referred to above:

Year	Expenditure	Men agents	Women agents	Boys' and girls' club agents	Extension specialists in states
1914	$ 480,000	500	200	?	?
1924	18,660,000	2,239	921	126	800

While the figures given are for 1924, it is not likely that a summary of the 10-year period ending with 1934 would show much of a change in the relative status of extension and research as evidenced by the funds expended.

It is obvious that organized extension has developed at a high rate of speed as compared with the development of organized research. This is not surprising. Successful extension efforts make an immediate appeal to the public. The public does not understand the philosophy that is involved in inbreeding field or sweet corn; the generally accepted explanation of heterosis or hybrid vigor; the reason or necessity for from 6 to 10 or more years of experimentation, but it does recognize at once, after a demonstration or two, the value of double-crossed corn. The end product makes an immediate appeal. The careful, painstaking, and scientific research of the plant pathologist does not arouse much interest in the general public. But an

application of dust or spray that will stop the ravages of a destructive disease will command interest and approval at once. Such examples could be furnished by the score.

It is well known to all of us that extension activities naturally make their appeal to the public so strongly that the latter is often led to request aid for problems faster than research can provide the facts. By his public, the extension man is supposed to be able to answer all questions and solve all problems. Herein lies a pitfall. An extension man, unless he is well trained and blessed with a good sense of balance, may be tempted to extend beyond the limits of demonstrated knowledge, in order to meet the demands of his clientele. Most of us are familiar with this type of man who answers with assurance and authority every question put up to him by the farmer. Nearly every state has one of these. He is a thorn in the flesh to the research man, because he is usually a fine personality, aggressive, has a large following, and is right a little more than half of the time. The times he misses are forgotton, his hits are long remembered, as are the predictions of the local weather prophet or the cattle breeder who attempts to control the sexes of his calves by bizarre methods.

The development of organized extension has been so rapid that it has been difficult to develop the personnel to meet the demand. This has resulted in the employment of men whose experience and training have been inadequate. They may have had good organization ability and may have been endowed with energy and personality, indeed they should be, but they lacked sufficient basic knowledge of subject matter and had neither knowledge of nor sympathy for the methods of research. It is thus easy for them to drop into the pitfall mentioned above.

The research man has been over-shadowed and out-distanced by the extension man. This may have been inevitable on account of the very nature of things, some of which were mentioned above. Particular attention has been called to some of the faults of the extension man. It is only fair to state here that the research man has some responsibility in this connection. Perhaps it should be left for the extension representative to list the defects and faults to be found in the field of research, but as evidence that we are not a smug and self-complacent group, attention should be called to the following four points which will stand scrutinizing.

First of these is the apparent lack of appreciation on the part of some research men as to what the important problems really are. It is not scientifically wrong to assume that any Truth is worthy of discovery. But in agricultural research some regard should be had for the relative economic value of the problems presented. This reasoning leads us naturally to the second criticism of the research program, which is the ignorance or forgetfulness of the real purpose of agricultural research supported by public funds. The public pays the bill and is entitled to consideration. Of course, no one can say when and where the results of research may be applied. Some times very abstruse problems have been attacked and solved, which apparently had no possible chance of application in any way, but which later were applied in a manner so as to affect mankind very materially. Some of

the earlier discoveries of organic chemistry may be cited here. The research man was merely interested in chasing the carbon atom around the benzene ring But the gigantic dye business was later founded on the basis of his work. Nevertheless, in spite of this point of view, the research man in the agricultural college or experiment station should choose his problems with respect to the needs of the state so far as possible.

The third criticism of the research man concerns his attitude of ultra-conservatism Just as the extension man is apt to go off "half-cocked" on some proposition, so is there the tendency for the research man to withhold application of his discovery until he has checked, double-checked, and confirmed everything, even to the "speck on the nail of the toe on the foot on the leg of the flea on the hair of the tail of the dog" A happy medium in regard to this point should be striven for. Care should be taken not to release the results of research for application before they have been substantiated. One mistake along this line will neutralize the benefits of ten successful ventures. But the investigator should be constantly on the alert to put important findings into use as promptly as possible.

The fourth criticism against the research man is the tendency he sometimes has to develop a superiority complex, to consider his work on a higher level than that of the extension worker. There is only one remedy for such persons and that is to let them go out and attempt to put across a piece of extension.

To summarize this discussion up to this point, it seems fair to state that the coordination between the extension man and the research man is not all that it should be. Probably the best explanation of this situation can be based upon the relatively rapid development of organized extension work and this rapid development is easily explained on the basis of the strong appeal to and intimate contact with the paying public which the extension enterprise has. Organized extension has reached a point after a 20-year period where it is overshadowing research and making demands which the latter is unable to meet.

The remedy for this situation does not lie in an antagonistic or destructive policy. Organized extension should not be curtailed. Rather, on the other hand, it should be expanded to meet pressing needs. Neither in these times of stress, with all the talk about overproduction and the need for a "research holiday", should it be forgotten that research is the foundation, the basis of all extension activity and that the super-structure now has possibly builded higher than its foundation justifies. The research program should not be curtailed but should be expanded to meet the pressing needs of extension. One only has to mention the present national soil erosion program to bring to mind scores of problems which must be solved by research before the findings can be extended and applied.

Another remedy lies in providing a closer relationship between extension and research men. The ideal arrangement in the opinion of the writer is to have them together in the same subject-matter department, where research men, teachers, and extension men are closely associated. Much is to be gained by this close association.

Particularly does it tend to keep the extension man up to date in the field. This acts as a balance wheel to prevent "over-extending." In turn the research worker is brought into intimate contact with problems from the outside which might have otherwise entirely escaped his attention but which are thus brought to him. This broadens and strengthens his work. In addition to this there should be close coordination and cooperation of related subject-matter departments. Very few, if any, departments of agricultural colleges of today are organized on a wide enough basis to include all the fields of knowledge necessary to the solution of problems. Thus, the plant breeder at Cornell, for example, finds it highly desirable to cooperate closely with the departments of Vegetable Crops, Agronomy, Plant Pathology, Entomology, Floriculture, and Botany. Such cooperation is as valuable to the extension worker as it is to the investigator.

It was stated above that the rapid development of organized extension had resulted in the bringing in of men with inadequate training and experience. This raises the question as to what should be the training of an extension specialist in the agricultural college. The writer believes that he should have an educational background and training equal to that of the resident teacher or investigator. He should be thoroughly grounded in the subject matter of his department. He should be familiar with the methods and results of research in his field, and if possible, he should keep his "hand in" by carrying along a piece of research. With this training and experience he would realize the limitations of research. From his contacts in the field he would bring back many problems to be investigated. This would be a stimulus to the research of the department. At times the extension man might find it desirable to do considerable educational work. Reference has already been made to the use of double-crossed corn. This may be handled by rule of thumb methods, but many farmers will not understand the reasons for these and will attempt short cuts which can only result in failure. Some have expressed the opinion that state-wide educational campaigns on the theories and principles involved in the production of double-crossed corn may be desirable. Such a campaign would challenge the best efforts of an extension man. It is obvious from the above that the training sugges-gested for the extension man is the equivalent of that obtained in connection with the doctorate degree and of the same grade as that usually expected of the teacher or investigator.

Finally, the extension force of an agricultural college should not present a divided front to the public. No matter what the internal departmental organization may be, and it does vary considerably in different colleges, boundary lines should be eliminated so far as the public is concerned. Where the extension men are placed with the subject-matter departments, instead of in a central extension office, this final suggestion offers some difficulties, but these are not so great as those that are sure to arise through lack of intimate contact and association with the subject-matter department. This united front can be efficiently maintained by sustained, close cooperation between related subject-matter departments or divisions. Such cooperation is a practical necessity.

In conclusion, one can express only the greatest appreciation and respect for the accomplishments of both agricultural research and extension in the United States. Probably in no other country up to the present time have the needs of the farmer been so fully met in this regard. Such problems as have arisen and such criticism as has been made are due to a lack of a real and continuing appreciation of the fundamental relationship of these two fields of service. One is necessarily based upon the other. This fact cannot be ignored. That it has been, is due to the very nature of the work in the two fields. The work of the research man is an unknown book to the layman and will remain so, for the most part, for a long time to come. For this reason it does not make an appeal to the public. The effort of the extension man, on the other hand, is immediately appreciated by the public, which can at once see and evaluate the advantages resulting from it. This situation tends to over-shadow research activity and to set up extension work as a separate and entirely independent field. The remedy lies in the complete recognition of the fundamental relationship between the two fields. This can best be brought about by closer coordination of research and extension workers based upon subject-matter organization and by providing that the latter group be as well trained in the fundamentals of the subject as is the former group.

A COMPARISON OF GLASS AND QUINHYDRONE ELECTRODES FOR DETERMINING THE pH OF SOME IOWA SOILS: I. A COMPARISON OF DIFFERENT TYPES OF GLASS ELECTRODES[1]

Harold L. Dean and R. H. Walker[2]

DURING the past decade the quinhydrone electrode has been used extensively for determining the hydrogen-ion concentration of soils. It is considered to be well adapted to the study of reaction in soils because of its simplicity and ease of operation, and also because of its accuracy in most soils. As is well known, however, its use is restricted to soils having a reaction more acid than pH 8.0 to 8.5, and to soils containing no oxidizing or reducing substances in sufficient concentration to interfere with the normal dissociation of the quinhydrone.

In recent years a number of investigators, notably Karraker (14),[3] McGeorge (20), Baver (1), Heintze and Crowther (11), and Naftel, Schollenberger, and Bradfield (23) have noted that erroneous results were obtained where the quinhydrone electrode was used to determine the hydrogen-ion concentration of certain soils having a neutral or even an acid reaction. The presence in soils of comparatively large amounts of the higher oxides of manganese has been found to cause an error in the measurement of the hydrogen-ion concentration. Heintze and Crowther (11) attributed this error to the reduction of the higher oxides of manganese by the hydroquinone derived from the dissociation of the quinhydrone. Subsequently, the reduced manganese hydrolyzes to form manganese hydroxide which reacts with the soil acids. This explanation has been confirmed by the work of Naftel, Schollenberger, and Bradfield (23) and by that of Naftel (22).

In order to overcome the difficulties encountered in the use of quinhydrone for hydrogen-ion determinations in soils, it has been suggested that the glass electrode be used. As early as 1906, Cremer (5) found that a potential difference may be set up where two solutions are separated by a thin glass membrane, the potentials being a function of the hydrogen-ion concentration. Several investigators (2, 3, 4, 9, 12, 15, 18, 21) have found the glass electrode to give results equally as reliable as the hydrogen electrode Furthermore, they have found the glass electrode to be as rapidly operated as the quinhydrone electrode and more widely applicable than either of the other two. Naftel, Schollenberger, and Bradfield (23) found the glass electrode to be well adapted for soil reaction measurements and also to be free from the inherent errors of commonly used methods.

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[2]Research Fellow and Research Associate Professor of Soils, respectively. The authors are indebted to Dr. P. E. Brown for suggestions and criticisms offered in the course of this work and in the preparation of the manuscript.

[3]Figures in parenthesis refer to "Literature Cited", p. 435.

Many types of glass electrodes have been used in determining the hydrogen-ion concentration of soils. Probably the types most widely used are the (a) plain bulb, quinhydrone; (b) plain bulb, silver-silver chloride; (c) reëntrant, silver-silver chloride, and (d) the MacInnes-Dole type of membrane, silver-silver chloride. The composition of the glass used for glass electrodes is extremely important and much

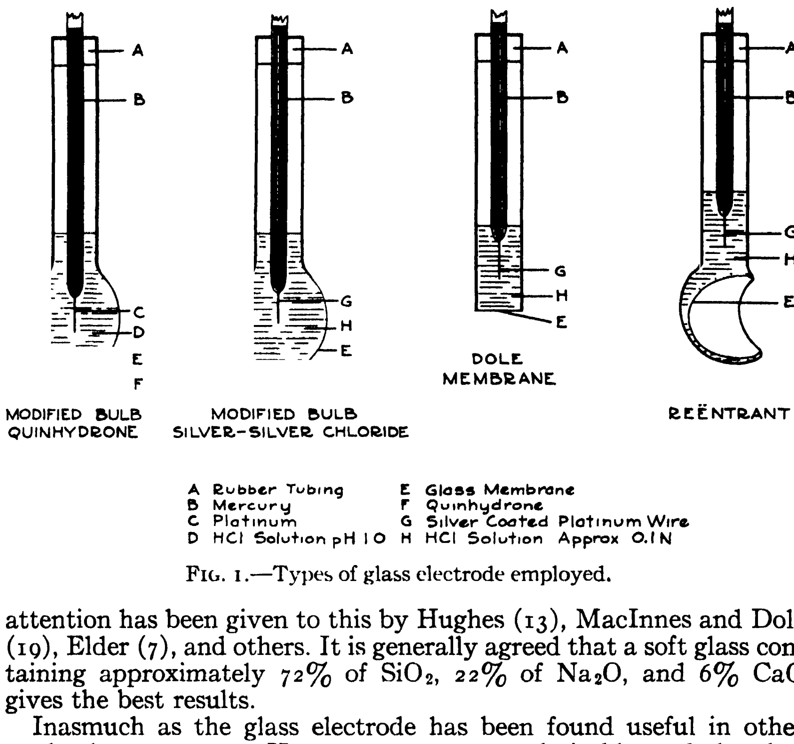


FIG. 1.—Types of glass electrode employed.

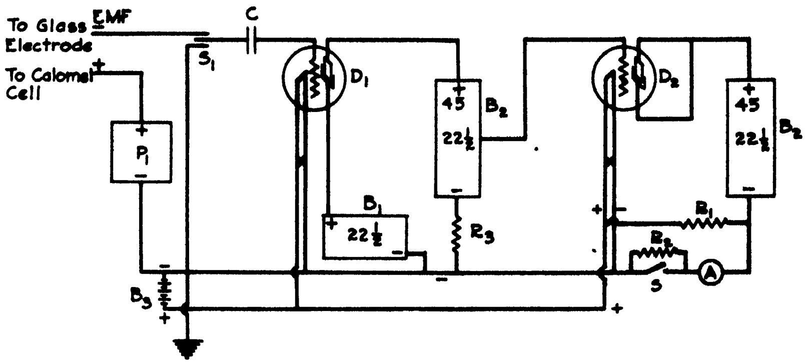
attention has been given to this by Hughes (13), MacInnes and Dole (19), Elder (7), and others. It is generally agreed that a soft glass containing approximately 72% of SiO_2, 22% of Na_2O, and 6% CaO gives the best results.

Inasmuch as the glass electrode has been found useful in other work where accurate pH measurements were desirable, and also that it has been used to a limited extent for measuring the reaction of soil, it was thought advisable to investigate further the feasibility and practicability of using it in pH determinations on soils. The initial study made in this investigation was a comparison of different types of electrodes and a study of their suitability for pH measurements in soils. The results obtained are presented in this paper.

EXPERIMENTAL PROCEDURE

In this study the adaptability of four types of glass electrodes for pH determination in soil was investigated. The types used were (a) the modified bulb, silver-silver chloride, as used by Goodhue (10); (b) the modified bulb, quinhydrone made according to the specification of the Leeds and Northrup Co.; (c) the reentrant, silver-silver chloride, a modification of the Kerridge (16) electrode; and (d) the MacInnes-Dole (17) type of membrane, silver-silver chloride. A diagrammatic sketch of these types of electrodes is given in Fig. 1. The electrodes were made from Corning glass No. 015.

Glass electrodes have a high electrical resistance, the extent of which is from 2 to 100 megohms. It is impossible, therefore, to make measurements with the ordinary galvanometers and potentiometers commonly found in laboratories. In order to control high resistance the quadrant electrometer or the vacuum tube amplifying unit must be used. It is also essential that the apparatus be shielded and insulated from any outside interference.



A	Ammeter	P	Potentiometer
B_1	22½ Volt "B" Battery	R_1	500 Ω Fixed Resistance
B_2	45 Volt "B" Battery	R_2	5,900 Ω " "
B_3	2 Volt Storage Cell	R_3	150,000 Ω " "
C	Condenser 0.01 MFD	S	Switches
D_1	UX32 Tube	S_1	Grid Switch
D_2	UX33 Tube	X	Filament Control

FIG. 2.—Circuit diagram of the vacuum tube amplifying unit employed in determining pH with the glass and quinhydrone electrodes.

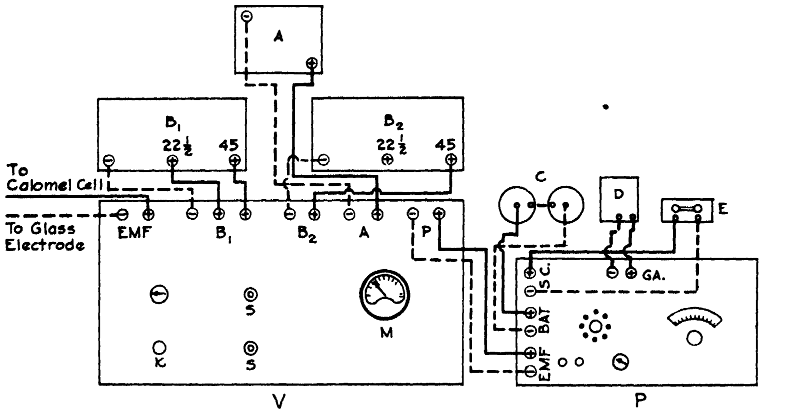
Throughout the experiments reported here the vacuum tube circuit was used with the potentiometer. It was constructed according to Goodhue's (10) modification of Ellis and Kiehl's (8) vacuum tube circuit. The circuit diagram of this apparatus is presented in Fig. 2. With this amplifying unit it is possible to measure cells with very high resistance with an accuracy within 1 millivolt. With the glass electrode greater accuracy than this is not necessary inasmuch as each electrode is standardized against a known buffer solution.

The potentiometer used with the vacuum tube amplifying unit was a Leeds and Northrup hydrogen-ion potentiometer. A wiring diagram of the complete setup is given in Fig. 3.

It was found desirable to make pH determinations with the glass electrode under controlled conditions of temperature; hence, the electrodes were kept in a Freas electric incubator and all the determinations were made at 25°C. In order to maintain the temperature within a narrow range of fluctuation a cooling coil was installed in the incubator through which cold water could flow at a controlled rate.

Samples of five different soil types were used in the experiment, namely, Tama silt loam, Grundy silt loam, Shelby loam, Marshall silt loam, and Carrington loam. The soils were air-dried and passed through a 20-mesh sieve. A 30.0-gram sample of soil was placed in a 150-cc extraction flask and mixed with 75 cc of CO_2-free distilled water. The mixture was shaken for 1 minute and then allowed

to stand for 2 hours at which time the supernatant liquid was poured into a specially constructed "U-shaped" tube and the glass electrode introduced into the liquid. The electrode was so adjusted that the surface of the liquid inside the electrode was level with the surface of the liquid outside. Then the KCl-agar bridge making contact with the calomel half-cell was introduced and the potential measured. The voltage readings given by the electrodes were calculated to pH by the Youden and Dobroscky (24) method.



A 2 Volt Storage Cell
B_1 & B_2 45 Volt "B" Battery
C Dry Cells
D Galvanometer
E Standard Cell

P Potentiometer
V Vacuum Amplifying Tube
S Switches
K Key
M Ammeter

FIG. 3.- Wiring diagram of the electrometric apparatus, including the hydrogen-ion potentiometer and the vacuum tube amplifying unit employed determining pH with glass and quinhydrone electrodes.

RESULTS

In comparing the reliability of the different types of glass electrode for measuring the pH of soils, the potential of quadruplicate samples of each soil was determined by each of the four types of electrode, the electrodes being used simultaneously on each sample of soil. The results are shown in Table 1.

In the case of the Tama silt loam, the modified bulb, silver-silver chloride electrode gave a slightly higher average pH value and the reentrant type of electrode gave a slightly lower average pH value than the other electrodes. In the case of the Carrington loam, the reentrant type of electrode gave a slightly higher average pH value and the MacInnes-Dole membrane type gave a slightly lower average value than the other electrodes. The modified bulb, silver-silver chloride electrode gave the highest average pH value of the electrodes on Shelby loam and the modified bulb quinhydrone type the lowest average value. In the case of the Grundy silt loam, the modified bulb, quinhydrone electrode gave a higher average pH value than the other electrodes and the modified bulb and reëntrant electrodes the lowest average pH value. On the Marshall silt loam, the MacInnes-Dole

TABLE 1.—*The pH of quadruplicate samples of five soils as determined by four types of glass electrode.*

Sample No.	Types of glass electrode			
	Modified bulb Ag/AgCl	Reëntrant	Modified bulb quinhydrone	MacInnes-Dole
		Tama Silt Loam		
1	5.03	4.98	5.06	5.09
2	5.09	4.99	5.01	4.77
3	5.06	4.99	5.03	5.01
4	5.04	4.99	5.06	5.04
Average....	5.06	4.99	5.04	4.98
		Carrington Loam		
1	5.08	5.13	5.09	5.06
2	5.08	5.09	5.13	5.11
3	5.06	5.06	5.01	5.06
4	5.11	5.06	5.08	5.04
Average....	5.08	5.09	5.08	5.07
		Shelby Loam		
1	5.82	5.81	5.78	5.84
2	5.87	5.70	5.74	5.79
3	5.96	5.81	5.84	5.81
4	5.89	5.87	5.80	5.79
Average....	5.89	5.80	5.79	5.81
		Grundy Silt Loam		
1	5.40	5.38	5.47	5.43
2	5.35	5.38	5.48	5.47
3	5.40	5.35	5.45	5.45
4	5.31	5.37	5.47	5.45
Average....	5.37	5.37	5.47	5.45
		Marshall Silt Loam		
1	7.46	7.36	7.45	7.56
2	7.46	7.34	7.41	7.53
3	7.46	7.29	7.43	7.56
4	7.45	7.23	7.36	7.55
Average....	7.46	7.30	7.41	7.55

membrane electrode gave the highest average pH value and the reëntrant type the lowest average value. It appears that no one type of electrode gave consistently higher or lower results on the various soils than the other electrodes.

While making the determinations on the Marshall silt loam, it appeared that the electrodes were not functioning the same as they had in the acid soils. Considerable drift occurred with all electrodes, and inasmuch as the drift in potential was rather large at times, the readings were taken at the point of apparent equilibrium. From 2 to 8 minutes elapsed from the time the electrodes were immersed in the

soil suspension until the readings were finally taken. In a later experiment it was found, however, that the potential became constant after approximately 10 to 15 minutes. The cause of the potential drift was not definitely determined.

In order to determine the extent of variation of the pH values obtained with the different electrodes, the total range of variation, the probable error of the mean, and the standard deviation of the items were calculated from the total number of pH values for each soil. These data are shown in Table 2.

TABLE 2.—*The variation in pH as determined on quadruplicate samples of each soil by four different types of glass electrodes.*

Soil type	Variation in pH	Probable error of the mean	Standard deviation
Tama silt loam	0.32	0.012	0.024
Carrington loam	0.12	0.005	0.032
Grundy silt loam	0.17	0.009	0.056
Shelby loam	0.26	0.010	0.060
Marshall silt loam	0.33	0.016	0.098

As may be noted, the total range of variation for Carrington loam was within 0.12 pH; 50% of the total number varied within 0.005 of a pH above or below the mean as indicated by the probable error and two-thirds of the total number varied within 0.032 pH above or below the mean as indicated by the standard deviation. The data secured with the other soils varied slightly more than this and were most variable in the case of the Marshall silt loam where the range of variation was 0.33 pH. Even with this soil, however, the probable error of the mean was not large, being 0.016 pH.

From the data obtained it may be concluded that all four types of glass electrode employed in this test gave similar results with the soils studied, and further, that the extent of the variations in the results obtained in any case were extremely small and well within the limits of accuracy necessary.

Inasmuch as all the electrodes gave comparable results, it was necessary to select one type of electrode for further experiments. From the standpoint of practicability in preparation and use, the modified bulb silver-silver chloride type of electrode has some advantages not possessed by the other electrodes; therefore, it was considered the most desirable for further use and study. It is stronger, more durable, and easier to construct and maintain than the other types of electrodes.

In order to have a supply of these electrodes available in the laboratory, 11 electrodes were constructed and treated with a hydrochloric acid solution of pH 1.0 for 24 hours. The potentials of the glass and quinhydrone electrodes were then determined in two buffer solutions, potassium acid phthalate and phosphate. The results are presented in Table 3.

Assuming that the quinhydrone electrode indicated the proper pH value of these buffer solutions, it may be noted that 8 of the 11 glass electrodes gave pH values within 0.02 of the proper values and that

TABLE 3.—*The pH values obtained with eleven glass electrodes constructed from one stock of glass in an unknown phosphate buffer.*

Electrode No.	Potential in millivolts		Difference in potentials	pH of unknown phosphate buffer
	Standard acid phthalate buffer	Unknown phosphate buffer		
I	0.1438	0.3616	0.2178	7.67
II	0.1451	0.3631	0.2180	7.67
III	0.1325	0.3501	0.2171	7.65
IV	0.1352	0.3542	0.2190	7.68
V	0.1459	0.3629	0.2170	7.65
VI	0.1459	0.3480	0.2021	7.40
VII	0.1500	0.3675	0.2175	7.67
VIII	0.1490	0.3649	0.2159	7.63
IX	0.1445	0.3623	0.2178	7.67
X	0.1321	0.3401	0.2080	7.50
XI	0.1201	0.3389	0.2188	7.68
QH	0.2184	0.0005	0.2179	7.67

3 electrodes failed to function properly. It is concluded from these results that when several electrodes are constructed properly from one stock of glass and tested in buffer solutions, they will, in the main, function similarly and can be depended upon, with a few exceptions, to give accurate results.

SUMMARY AND CONCLUSIONS

1. A study was made of the adaptability of the glass electrode for determining the hydrogen-ion concentration of soils.

2. A potentiometric setup suitable for use with the glass electrode was described. This included a vacuum tube amplifying unit in combination with a Leeds and Northrup hydrogen-ion potentiometer and other commonly used instruments.

3. Data are presented which show that four different types of glass electrode gave similar results when the hydrogen-ion concentration of soils was determined. The variability in pH of replicate samples of soil was extremely small with each type of electrode.

4. The modified bulb, silver-silver chloride type of electrode was found most practicable and desirable because of its ease of construction, strength, durability, and maintenance.

5. Several glass electrodes of the modified bulb type constructed from one stock of glass were found, in the main, to function similarly, and the data indicate that these electrodes may be depended upon to give accurate results.

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CONVERSION OF SOIL POTASH FROM THE NON-REPLACEABLE TO THE REPLACEABLE FORM[1]

F. A. E. Abel and O. C. Magistad[2]

PINEAPPLE plants in Hawaii often contain at maturity more potash per acre than was present in replaceable form in the surface acre foot of soil. Thus, Horner (7)[3] found that 9,600 mature pineapple plants grown on a plat receiving no fertilizer application contained 1,672 pounds of K_2O per acre. Soil from the same field on which these plants grew contained 1,036 pounds of replaceable potash per acre foot. In this experiment the root systems of the pineapple plants only occasionally penetrated to a depth greater than 12 inches, and it appears very unlikely that any appreciable feeding occurred in the second foot of soil. These facts strongly suggest that considerable potash must become available to the plant from non-replaceable sources during the 2 years that the plant gains maturity. This paper presents data from two experiments showing to what extent this conversion takes place. Throughout this paper replaceable or exchangeable potassium is considered synonymous with available potassium. Water-soluble potassium is included with the replaceable form.

REVIEW OF LITERATURE

In 1910, Hopkins (6) stated that the equivalent of 0.25% of the total potassium in the surface soil could be made available during one season by practical field methods. He based this statement on a study of the results of successive crop yields and their analyses.

In 1918, Plummer (11) grew oats, rye, soybeans, and cowpeas on limed and unlimed potash-deficient soil to which potassium-containing minerals were added. Plant growth was better with some minerals than with others, and on the limed soils legumes grew better than nonlegumes. Plummer believed that legumes on limed soils had bigger root systems which enabled the plant to obtain more potash; and that lime had no effect on potash solubility.

Breazeale and Magistad (2) in 1928 demonstrated that potash in the mineral form could be converted to the replaceable form. They digested pure, finely ground orthoclase powder in alkaline solutions and obtained a marked production of replaceable potassium.

More recently, Martin (9), Fraps (3), Gedroix (4), and Hoagland and Martin (5) have shown by means of pot experiments that crops obtained some potassium from non-replaceable sources, or at least that the amount of potassium in the crops exceeded the decrease of replaceable potassium in the soil.

That the conversion of potassium from the replaceable to non-replaceable form, and *vice versa*, is highly probable, was shown by Bartholomew and Jans en in 1931 (1) while working with Arkansas soils. Heavy potash fertilization shifted the

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[1]Contribution from the Pineapple Experiment Station, University of Hawaii, Honolulu, Hawaii. Published with the approval of the Director as Technical Paper No. 84. Received for publication March 4, 1935.

[2]Assistant Chemist and Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 444.

equilibrium toward the non-replaceable form, causing some of the added water-soluble potassium to be fixed in a non-exchangeable manner.

Volk (13) made a thorough study of potash fixation and found that some soils fix a large share of the water-soluble potash applied to them in the form of the mineral muscovite.

EXPERIMENTAL

Two experiments were conducted and will be described separately.

EXPERIMENT I

Soils.—Two typical pineapple soils were used. These are described below:

Soil No.	Location	pH value	Total K_2O %	Replaceable K_2O in M.E. per 100 grams	Remarks
917	Fd. 85, Brodie, Oahu	6.27	1.56	1.27	Fertile
923	Fd. 74, Oahu	4.57	0.36	0.04	Less productive

Containers.—Four 20-inch galvanized iron wash tubs were used as containers. A short length of copper tubing was soldered to the center of the bottom of each as a drain. The containers were painted with Ebonol paint to prevent contact of the metal with the soil. One tub of each soil was limed at the rate of 9 tons of $CaCO_3$ per acre foot of 2,400,000 pounds while another was left unlimed. Each tub contained approximately 15 kilos dry soil.

Crop.—Soybeans were first used as a crop because of their capacity to remove potash rapidly. Fifty sprouted beans were planted in each tub per crop. These beans were inoculated with the soybean group of nodule-forming bacteria to provide the plants with adequate nitrogen. Five consecutive crops of soybeans were grown, harvested, and analyzed. After the fifth crop soybeans failed to grow well and other plants, such as rice, sudan grass, and sorghum were tried. In all nine crops were grown. In three tubs the last seeding produced no growth.

Fertilization.—No fertilizer was added until after the second crop when superphosphate containing 21.4% P_2O_5 was applied at the rate of 1,050 pounds per acre foot of 2,400,000 pounds and was thoroughly incorporated in the soil. After the fourth and sixth crops ammonium sulfate equivalent to 200 pounds of nitrogen per acre foot was added.

Analyses.—The content of replaceable potash in the soils at the beginning of the experiment was determined and likewise after each crop had been harvested. The leachates were analyzed for potassium as were also samples of seeds used for each crop. At each harvest the entire plant, roots included, was carefully removed from the soil, weighed, and analyzed for potassium content. Analyses for potassium were made by the cobalti-nitrite method as modified by Truog and Volk (12).

The dry weights of the plants, weight of potash removed by the plants, and potash found in the leachates are shown in Table 1. The weight of potash removed by the plants is the total potash found in the plants minus the potash content in the seeds.

TABLE 1.—*Dry weight per crop, weight of potash (K_2O) removed by plants, and weight of potash in leachate, all values in grams per tub.*

Plant	Soil No. 917					
	Limed			Unlimed		
	Dry weight	Potash removed by		Dry weight	Potash removed by	
		Plants	Leachate		Plants	Leachate
Soybeans......	17	0.095	——	17	0.068	0.207
Soybeans......	55	0.461	0.200	52	1.045	——
Soybeans......	102	1.400	——	86	1.161	0.006
Soybeans......	55	0.825	0.005	59	0.620	——
Soybeans......	33	0.470	——	20	0.270	——
Rice..........	47	1.438	——	39	0.242	——
Sudan grass....	23	0.841	0.005	185	1.058	0.006
Sorghum......	52	0.546	0.024	31	0.309	——
Sorghum......	122	1.301	0.025	0	0.0	0.010
Total.......	506	7.377	0.259	489	4.773	0.229

Plant	Soil No. 923					
	Limed			Unlimed		
	Dry weight	Potash removed by		Dry weight	Potash removed by	
		Plants	Leachate		Plants	Leachate
Soybeans......	30	0.083	——	14	0.257	——
Soybeans......	70	0.506	0.011	50	0.305	0.126
Soybeans......	108	0.357	——	43	0.400	——
Soybeans......	50	0.020	——	8	0.130	0.017
Soybeans......	21	0.063	——	9	0.112	——
Rice..........	42	1.081	——	4	0.155	——
Sudan grass....	56	0.100	0.009	20	0.120	0.038
Sorghum......	11	0.045	——	8	0.062	——
Sorghum......	0	0.0	0.033	0	——	0.149
Total.......	388	2.255	0.053	156	1.542	0.330

The displaced soil solution of soil No. 917 contained 15 p. p. m. of potash which was 2½ times as great as that of soil No. 923. A ratio of this type was expected judging from the levels of replaceable potassium in these soils. (See description of soils.)

Twenty-five months elapsed between planting the first crop, March 3, 1931 and harvesting the ninth crop, April 28, 1933. It will be seen from Table 2 that during this time potassium was released from non-replaceable sources in all soils, but that the quantity released was greater in the limed soils than in the unlimed.

It would appear that lime increases the rate at which non-replaceable potash becomes available, but Plummer (11) in his experiment suggests that the increased root area resulting from increased growth in the presence of lime may be a more correct explanation.

TABLE 2.—*Summary of data to show the amount of replaceable potash released from non-replaceable sources.*

	Soil No. 917		Soil No. 923	
	Limed	Unlimed	Limed	Unlimed
Soil content replaceable K_2O, grams:				
Beginning of experiment	6.075	6.075	2.989	2.989
End of experiment	2.002	1.308	1.364	1.199
K_2O removed, grams:				
By plants	7.377	4.773	2.255	1.541
In leachate	0.259	0.229	0.053	0.330
Total removed	7.636	5.002	2.308	1.871
Grams potash released:	3.563	0.235	0.683	0.081
Amount released in % of replaceable at beginning	259.8	6.6	15.5	1.8
Pounds K_2O released per acre foot annually (calculated)	58.6	3.9	23.9	2.7

In order to obtain further information, a new experiment was planned using nonleguminous plants This is described below.

EXPERIMENT II

In this second experiment on the ability of soils to replenish the store of available potash, non leguminous crops were grown on six soils. The experiment occupied a period of 20 months, from August 31, 1932 to May 10, 1934.

Soils —Six soils from four islands representing the major pineapple sections were used. They varied from one extreme to the other with respect to their supply of replaceable potassium. The percentage base saturation, given in the last column of Table 4, was obtained as the quotient of milligram-equivalents $\frac{(Ca+Mg+K_2O)\ 100}{Total}$.

A description and analyses of these soils is given in Tables 3 and 4.

TABLE 3.—*Location of soils used in Experiment 2.*

Lab. No.	Island	Section and field
621	Lanai	Fd. L-1
866	Maui	Honolua, Fd. 104
2204	Oahu	Pearl City, Fd. 80
2519	Kauai	Kauai Pineapple Co., Fd. 22D
5027	Kauai	Hanalei, Fd. 2
5028	Oahu	Kunia, Fd. 80

In Table 4 replaceable hydrogen to pH 7.0 is given. It was determined by adding increments of known quantities of barium hydroxide to the soil in solution and shaking well at intervals for 1 week. At this time pH values were determined, using hydrogen electrode, and the values for pH were plotted against amounts of barium hydroxide added. The quantity of replaceable hydrogen to pH 7.0 could then be read from the curve connecting the plotted points.

TABLE 4.—*The replaceable base status of soils used in Experiment 2, with determinations made at the conclusion of the experiment and results expressed in milligram-equivalents per 100 grams of soil.*

Lab. No.	Treatment	H	Ca	Mg	K_2O	Total	Per cent saturated	pH
				Cropped Soils				
621	Limed	None	20.06	1.01	0.31	21.38	100	7.40
621	Unlimed	0.78	16.06	1.20	0.28	18.32	96	6.91
866	Limed	0.83	11.68	0.65	0.07	13.23	92	6.58
866	Unlimed	2.06	5.77	0.94	0.10	8.87	77	6.18
2204	Limed	2.12	6.97	0.26	0.07	9.42	78	6.21
2204	Unlimed	5.05	2.60	0.31	0.10	8.06	37	4.95
2519	Limed	2.61	6.17	0.24	0.07	9.09	71	6.01
2519	Unlimed	3.93	2.84	0.28	0.03	7.08	44	5.08
5027	Limed	1.84	8.68	0.27	0.06	10.85	83	5.78
5027	Unlimed	4.42	3.55	0.29	0.06	8.32	47	5.26
5028	Limed	10.61	8.09	0.21	0.10	19.01	44	5.37
5028	Unlimed	8.84	3.40	0.36	0.08	12.68	30	4.99
				Fallow Soils				
621	Limed	None	20.32	0.96	1.32	22.60	100	7.50
621	Unlimed	1.35	14.92	0.90	1.22	18.39	93	6.56
866	Limed	1.61	11.22	0.61	0.60	14.04	89	6.42
866	Unlimed	2.25	4.88	0.69	0.59	8.41	73	5.12
2204	Limed	2.47	6.96	0.16	0.41	10.00	75	5.65
2204	Unlimed	4.21	2.91	0.20	0.40	7.72	45	4.38
2519	Limed	2.39	6.20	0.07	0.17	8.83	73	5.59
2519	Unlimed	4.79	1.78	0.23	0.21	7.01	32	4.68
5027	Limed	2.23	7.68	0.26	0.16	10.28	88	5.80
5027	Unlimed	5.60	2.95	0.27	0.13	8.95	37	4.75
5028	Limed	11.08	7.28	0.17	0.24	18.77	41	5.41
5028	Unlimed	15.92	2.22	0.21	0.22	18.57	14	4.71

The very low degree of base saturation of some soils, as indicated in Table 4, suggests that these might be unproductive. While soil No. 5027 is marginal with respect to pineapples, soil No. 5028 is classed as a moderately productive one for this crop.

Containers.—Mitscherlich pots (10) were used for containers. For each soil there were six pots, three limed and three unlimed. Of these, two limed and two unlimed were planted. The remaining limed and unlimed pots were kept fallow. The soils of fallow pots were exposed to the sun and rain.

Crop.—Sorghum was used as a crop. It was expected to remove potash rapidly and to grow well in these soils. A total of five crops was harvested, weighed, and analyzed as described in Experiment I.

Fertilization.—In order to obtain large yields it was necessary to supply nitrogen and phosphate by fertilization. Four applications of nitrogen were made, one for each crop after the first, at the rate of 100 pounds nitrogen per acre foot of soil. Only one application of superphosphate at the rate of 500 pounds of P_2O_5 per acre foot was made. This occurred while growing the first crop. The nitrogen was applied as ammonium sulfate and as ammonium nitrate.

Analyses.—The replaceable potash content of the soils at the beginning of the experiment was determined, and after removal of the

last crop the same soils were analyzed for replaceable potassium, hydrogen, calcium, and magnesium The potash content of all crops, seed samples, and leachates was determined and the sum of potash removed by the crops and in the leachates. The cobalti-nitrite method (12) was used for all potash determinations. Standard base replacement methods were used for the other elements. Crop yields and crop and soil analyses are given in Tables 5 and 6.

TABLE 5.—*Dry weights of crops grown in grams per pot.*

Soil No.	Limed		Unlimed	
	Total weight of crops	Av. weight of crop per pot	Total weight of crops	Av. weight of crop per pot
621	220		278	
621	273	247	249	264
866	330		245	
866	278	304	268	257
2204	245		147	
2204	242	244	166	156
2519	247		228	
2519	235	241	269	249
5027	238		225	
5027	248	243	229	227
5028	189		146	
5028	204	197	154	150
Total crop yield	2,949		2,604	

DISCUSSION

Turning to Table 5, we note that the yield per pot for five cuttings of sorghum varied from 189 to 330 grams on the limed soils and from 146 to 278 grams on the unlimed. The total yield on limed soils was 2,949 grams compared with 2,604 grams on the unlimed. Thus, we see that the better yield on limed soils was not restricted to legume crops.

The data bearing on quantities of potassium taken up by plants and liberated from the non-replaceable complex are shown as averages of two pots per treatment in Table 6.

The amount of potash removed in the crop in case of soil No. 621 bears a large ratio to the total amount of replaceable potash originally present. With potash-deficient soils, such as No. 5028, the amount removed by the crop exceeded the original quantity of replaceable potash. The quantity of replaceable potassium in the soil about a month after the completion of the test is shown in column 3, and this amount in some instances exceeds the original value. Of great interest are the values given in the last three columns showing the quantity of potassium which has been converted from a non-replaceable to a

TABLE 6.—*Amount of replaceable potash released from non-replaceable sources.*

Soil No.*	Soil content replaceable K_2O, grams		K_2O removed, grams			Grams K_2O released	Amount released in per cent replaceable at beginning	Lbs. K_2O released per acre foot annually (calculated)
	Beginning	End	By plant	Leachate	Total			
				Cropped Soils				
621-L	1.712	0.504	1.443	0.019	1.462	0.254	15	91
621-U	1.712	0.529	1.203	0.021	1.224	0.042	2	15
866-L	0.785	0.136	0.827	0.006	0.833	0.184	23	66
866-U	0.785	0.188	0.646	0.007	0.653	0.056	7	20
2204-L	0.163	0.132	0.476	0.005	0.481	0.450	276	162
2204-U	0.163	0.183	0.407	0.005	0.412	0.432	265	155
2519-L	0.182	0.141	0.324	0.013	0.337	0.296	158	105
2519-U	0.182	0.064	0.300	0.023	0.323	0.205	112	73
5027-L	0.059	0.089	0.210	0.009	0.219	0.249	421	93
5027-U	0.059	0.108	0.167	0.004	0.171	0.220	372	79
5028-L	0.092	0.196	0.238	0.009	0.247	0.351	383	127
5028-U	0.092	0.150	0.233	0.011	0.244	0.302	328	109
				Fallow Soils				
621-L	1.712	2.480	——	0.064	0.064	0.832	49	299
621-U	1.712	2.296	——	0.069	0.069	0.653	38	234
866-L	0.785	1.136	——	0.055	0.055	0.406	52	146
866-U	0.785	1.108	——	0.046	0.046	0.369	47	133
2204-L	0.163	0.774	——	0.025	0.025	0.636	390	211
2204-U	0.163	0.752	——	0.049	0.049	0.638	391	229
2519-L	0.182	0.322	——	0.049	0.049	0.189	104	68
2519-U	0.182	0.402	——	0.045	0.045	0.265	145	95
5027-L	0.059	0.304	——	0.019	0.019	0.264	447	95
5027-U	0.059	0.236	——	0.012	0.012	0.189	320	68
5028-L	0.092	0.454	——	0.042	0.042	0.404	439	145
5028-U	0.092	0.408	——	0.052	0.052	0.368	400	133

L = Limed.
U = Unlimed.

replaceable form. Adding the values in the last column, a mean release of 107 pounds of K_2O per acre foot per year for six limed soils is obtained as compared with 75 pounds of K_2O for the same six soils when unlimed. In Experiment I, Table 2, the potash release was equal to 15.5 and 259.8 pounds K_2O per acre foot annually on the two limed soils, and on the same soils unlimed, 1.8 and 6.6 pounds, respectively. These values are of the same order as those reported by Hoagland and Martin (5) and by Fraps (3).

Jenny and Shade (8) have recently reviewed the conflicting literature on the effect of lime on potassium availability. In their experiment free calcium was able to replace potassium, but the study did not include conversion of potash from non-replaceable to available forms.

It was believed that an equilibrium existed between potassium in the non-replaceable and the replaceable form in the fallow soils. If no losses of replaceable potash occurred, little or no potash was expected to be converted from the non-replaceable to the replaceable state. In fact, Volk (13) indicates that under conditions of alternate wetting or drying such as these fallow soils were subject to, the po-

tassium is apt to become fixed. It was surprising, therefore, to find that in these fallow soils the amounts of potassium released from non-replaceable form were greater than in the cropped pots. (See column 9, Table 6.)

In these fallow pots, as well as in the cropped pots, potash release was greater in the limed soils. Clearly here the rate of release has no relation to root surface. The authors suggest that under conditions of alternate wetting and drying, such as occurred with the fallow pots, the following process takes place: During wetting some potash goes into solution from non-replaceable sources. On drying, the concentration of potash in the soil solution increases, some goes into the replaceable complex, and the next time the soil is wetted this does not all go back into the soil solution. Furthermore, with alternate wetting and drying under alkaline conditions base exchange material can be formed.

A study of Table 4 reveals the fact that without exception the limed soils have greater total exchange capacities than the unlimed. This can be explained on the assumption that additional base exchange material has been produced under the less acid conditions.

An attempt was made without success to analyze the effect of various factors, such as percentage base saturation and the level of replaceable potash, on rate of potash conversion from non-replaceable sources. It appears that cropping has little effect and that conditions for alternate wetting and baking are more effective in accelerating this process.

SUMMARY

Two experiments were conducted in the greenhouse using eight pineapple soils all derived from basaltic lavas. In the first experiment successive crops of soybeans were grown on two soils, one well supplied and one deficient in replaceable potassium, each with and without lime. The soils in this experiment received no potassium as fertilizer but did receive nitrogen and phosphorus. A balance sheet of readily available potash was kept.

In a second experiment similar to the first, six diverse soils were used, and two pots of each soil, limed and unlimed, were cropped with sorghum. One set of each soil remained fallow.

The conclusions were that about 100 pounds of K_2O per acre foot was made available from non-replaceable sources annually in the case of limed soils and about 75 pounds in the case of natural acid soils. The results were of the same order in the case of fallow soils, and with soils cropped with legumes on the one hand and nonlegumes on the other.

Soils having a very low amount of replaceable potash at the beginning of the test were able to release potash from non-replaceable sources as readily as soils rich in replaceable potash.

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DECOMPOSITION OF THE BASE-EXCHANGE COMPOUNDS OF SOILS BY ACIDS AND ITS RELATION TO THE QUANTITY OF ALUMINA AND SILICA DISSOLVED[1]

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THE base-exchange properties of soils are generally believed to be in the colloidal complex, and due both to clay and to organic matter. Mattson (13)[3] found the base-exchange capacity of colloidal clay to range from 0.164 to 1.102 M. E. per gram and the exchange capacity of humus to range from about 2.5 to 4.5 M. E. per gram, while McGeorge (12) reports the exchange capacity of ligno-humates to go as high as 4.20 M. E. per gram. Robinson (15, p. 110) found a fairly good agreement to occur with 13 soils and poor agreement to occur with 4 soils between the base-exchange capacity as estimated and that calculated by the equation $T = 0.57K + 4.55C$, in which T is the exchange capacity, K the clay content, and C the total carbon.

The base-exchange properties of clay are believed to be due to salts of one or more complex alumino-silicic acids. Any treatment which tended to destroy the base-exchange capacity of the clay might be reflected in the quantities of alumina and silica brought into solution by the treatment. The objects of the work here reported were to ascertain, first, the relation between the total base-exchange capacity and the iron and aluminum oxides dissolved from soils, and, second, the relation between the loss in exchange capacity and the materials dissolved by different strengths of acid alone and followed by 0.5 N sodium hydroxide. The information secured throws some light upon the nature of the base-exchange complex.

RELATION OF TOTAL EXCHANGE CAPACITY TO QUANTITY OF IRON AND ALUMINUM OXIDES SOLUBLE IN STRONG HYDROCHLORIC ACID

The relation between the total base-exchange capacity and the quantity of iron and aluminum oxides soluble in hydrochloric acid of 1.115 sp. gr. was determined. The total exchange capacity was ascertained by leaching with neutral normal ammonium acetate, washing out the excess ammonium acetate, and determining the absorbed ammonia by distillation with magnesium oxide. The total exchange capacity is expressed as M. E. per 100 grams of soil. The quantity of soluble iron and aluminum oxide was determined in the filtrate from 10 grams of soil digested in 100 cc of 1.115 sp. gr. hydrochloric acid for 10 hours in a boiling water bath. The percentages of the combined oxides of iron and aluminum soluble by this treatment of 259 soils were compared with the total exchange capacity.

[1]Contribution from the Division of Chemistry, Texas Agricultural Experiment Station, College Station, Texas. Received for publication March 22, 1935.
[2]Chief of Division and Chemist, respectively.
[3]Figures in parenthesis refer to "Literature Cited", p. 454.

Of 92 soils with less than 10 M. E. exchange capacity, 59 contained less than 3% iron and aluminum oxides soluble in the acid used, and 86 contained less than 6%. Of 29 soils with more than 40 M. E. exchange capacity, none contained less than 9% of soluble iron and aluminum oxides and 25 contained more than 12%. The correlation coefficient was + .878 ± .010, indicating a very close association between the exchange capacity and the content of soluble iron and aluminum oxides.

DECOMPOSITION OF THE EXCHANGE COMPLEX BY VARIOUS STRENGTHS OF ACID AND RELATION OF THE EXCHANGE CAPACITY TO MATERIAL DISSOLVED

The exchange complex of the soil has already been shown to be very little affected by treatment for a short time with 0.2 N hydrochloric acid at room temperature (6, p. 37). It seemed desirable to ascertain the effects of different strengths of acid upon the exchange capacity and to study further the relation between the exchange capacity and the materials dissolved. For this purpose about 12 soils were selected of various origins and high in base-exchange capacity. Ten-gram portions were digested 10 hours in a boiling water bath with 100 cc of hydrochloric acid of 0.2, 1.0, 1.75, 3.5, 7.0, and 8.75 normality. With 0.2 N acid sufficient additional acid was used to allow for the basicity of the soil. After digestion, the residue was filtered off and washed. The exchange capacity of the residue was determined by the ammonium acetate method. Silica and iron and aluminum oxides were determined gravimetrically in the filtrates. Iron was determined by reduction with zinc and titration with potassium permanganate. Aluminum oxide (with some titanium oxide) was estimated by subtracting the ferric oxide from the combined iron and aluminum oxides.

The reduction in exchange capacities of the soils caused by the treatment with acid are given in Table 1. It is seen from the table that digestion with the hot 0.2 N hydrochloric acid destroyed comparatively small portions of the exchange capacity, the average for the 12 soils being 17%. The decomposition, however, was higher than that due to unheated 0.2 N hydrochloric acid. The 1.0 N acid destroyed about half of the exchange capacity. With acid of 1.75 N, 3.5 N, 7.0 N, and 8.75 N, the average percentages of exchange capacity destroyed were 63, 74, 80, and 80, respectively. There was a comparatively rapid increase in destruction of the exchange capacity with increase in the strength of the acid until about 20% of the exchange capacity remained, after which a considerable increase in the strength of the acid caused no further destruction.

The base-exchange capacities of the residues from the same treatment varied with different soils. With dilute acid, especially, individual soils differed considerably. For example, 64% of the exchange capacity of soil No. 29438 was left after treatment with 0.2 N acid, while 96% of that of No. 23950 was left after the same treatment. Considerable differences between the percentages left in different soils also occurred with the 1.0 N acid (46 to 66%), the 1.75 N acid

TABLE 1.—*Reduction of exchange capacity of soils by digestion with hydrochloric acid.*

Laboratory No.	Soil	Original exchange capacity M.E.	Exchange capacity of residue as per cent of capacity of original soil					
			0.2N	1.0N	1.75N	3.50N	7.0N	8.75N
25887....	Victoria clay loam	19.3	17	49	63	66	72	74
31321....	Amarillo silty clay loam	20.2	19	46	60	72	77	77
29438 ..	Lufkin fine sandy loam	23.9	36	41	53	73	84	86
31327....	Randall clay	27.6	14	34	65	74	81	81
29427....	Crockett clay loam	28.9	19	53	53	64	73	75
23950 ...	Frio clay	31.5	4	38	58	76	80	78
23952....	Houston clay	34.7	12	40	61	76	83	85
26089....	Catalpa clay	35.1	16	47	58	71	78	78
23946....	Miller clay	36.0	7	37	63	77	77	75
26085....	Houston clay	40.0	11	54	70	76	82	83
26823....	Lake Charles clay	45.2	21	56	68	73	78	80
26079....	Bell clay	46.4	23	53	76	80	85	86
Averages			17	47	64	74	80	80

(24 to 47%), and the 3.5 N acid (20 to 36%), but the order of the soils is not the same as with the 0.2 N acid. With the 7.0 N and 8.75 N acids, however, the variation was somewhat less, being from 15 to 28% with the 7.0 N acid and 14 to 26% with the 8.75 N acid.

From Table 2 it is seen that a high degree of relationship between the percentages of alumina dissolved and the decrease in the exchange capacity occurs with all strengths of acid for all the soils. If the quantity of alumina brought into solution by the strongest acid, 8.75 N, be given a comparative value of 100, the average relative values for the quantities dissolved by the other strengths, except 7.0 N where the value is approximately the same as for 8.75 N, are in approximately the same ratio as the figures for the relative destruction of the exchange capacity by the acid treatments.

If, instead of 100, the alumina in solution with 8.75 N acid be given a comparative value of 80, the same as the percentage of destruction of the total exchange complex by that acid, the relation between the quantities of alumina in solution and the exchange complex destroyed are comparatively close, except with the first two acids, 0.2 N and 1.0 N, where the relative destruction of exchange complex is nearly double that of the solution of alumina. The correlation coefficient between the loss of exchange capacity and the quantity of alumina brought into solution by the various strengths of acid was $+ .859 \pm .029$, showing a very high relation.

The relation between the decrease in total exchange capacity and the quantity of alumina in solution is shown more clearly when the decrease in M. E. of exchange capacity is expressed as percentages

TABLE 2.—*Percentage of alumina dissolved by acids of different strengths.*

Laboratory No.	Strength of acid					
	0.2N	1.0N	1.75N	3.50N	7.0N	8.75N
25887	0.91	1.94	3.57	4.22	5.27	4.83
31321	1.03	2.61	5.32	6.43	6.87	6.89
29438	0.59	1.91	3.51	5.17	5.23	5.95
31327	1.06	3.37	6.08	8.21	8.74	8.15
29427	0.56	3.78	4.37	6.57	7.65	7.46
23950	1.33	1.35	4.29	6.28	7.95	7.84
23952	1.21	2.44	5.21	7.36	7.82	7.58
26089	0.95	2.52	5.60	9.05	9.94	9.36
23946	1.10	3.03	7.21	10.01	11.53	11.05
26085	1.03	3.24	7.24	7.89	7.89	8.22
26823	1.09	3.67	7.90	7.71	8.68	8.04
26079	1.16	4.11	7.49	9.23	9.84	9.56
Average	1.00	2.73	5.65	7.35	8.12	7.74
Relative quantity, 8.75N = 100	13	37	73	95	105	100
Relative quantity, 8.75N = 80	10	30	58	76	84	80
Relative decrease of exchange capacity	17	47	64	74	80	80

of the alumina dissolved, also in M. E., 6 M. E. being assumed for a milligram molecule of alumina. These data are given in detail in Table 3. The percentages for the individual soils vary widely from the average with the 0.2 N and 1.0 N acids, but are reasonably close to the average with the stronger acids. The average percentage decreases from 10.02 to 5.54 as the strength of the acid increases. If

TABLE 3.—*Decrease in M.E. of exchange capacity in percentage of M.E. of soluble alumina.*

Laboratory No.	Strength of acid					
	0.2N	1.0N	1.75N	3.50N	7.0N	8.75N
25887	6.32	8.37	5.74	5.14	4.50	5.02
31321	6.41	6.10	3.85	3.82	3.82	3.78
29438	24.80	8.75	6.06	5.68	6.42	5.78
31327	6.18	4.75	4.95	4.14	4.24	4.54
29427	13.50	6.90	5.89	4.70	4.63	4.86
23950	1.67	15.20	7.10	6.40	5.28	6.02
23952	9.85	9.65	6.22	6.04	6.08	6.50
26089	10.00	11.00	6.03	4.62	4.62	4.93
23946	3.84	7.46	5.26	4.32	3.78	3.83
26085	7.05	11.10	6.45	6.45	6.94	6.74
26823	14.80	11.20	6.55	7.18	6.80	7.50
26079	15.80	10.10	7.96	6.74	6.74	6.97
Average	10.02	9.17	6.01	5.44	5.32	5.54

the decrease in exchange capacity caused by each increase in strength of the acid is compared with the increase in alumina dissolved, the 1.0 N acid is found to dissolve the aluminum compounds which have the greatest effect on the exchange capacity, this being where the exchange capacity lost was, on an average, 10.0% of the M. E. of alumina dissolved. The effectiveness of the alumina decreased with an increase in the strength of the acid. That is to say, the compounds dissolved by the stronger acids have lower base-exchange capacities in proportion to the alumina dissolved than those which are dissolved by the weaker acids.

There was no relation between the decrease in total exchange capacity and the quantity of either ferric oxide or silica dissolved. The maximum quantity of ferric oxide was dissolved by 1.0 N acid. The quantities of silica dissolved by the acids were very small and decreased as the strength of the acid increased.

EFFECT OF DIGESTION WITH 0.5 N SODIUM HYDROXIDE FOLLOWING ACID DIGESTION

The less stable compounds when affected by acid digestion may rearrange into compounds which are similar but more stable and have less exchange capacity, or they may be broken down completely, leaving silica or silicic acid in the soil.

Treatment with acid did not completely destroy the base-exchange capacity of the soils studied, about 20% remaining after 10 hours heating with the strongest acid used. It has been claimed (5) that the power of the soil to exchange bases is due not to a base-exchange complex (consisting of compounds of alumina, bases, and silica), but to silicic acid. If such active silicic acid is present, it might be soluble in sodium hydroxide, so that extraction with sodium hydroxide would decrease the base-exchange capacity of the soil. In order to test this point, a set of untreated soils was digested in a boiling water bath for 10 hours with 0.5 N sodium hydroxide and the soluble alumina and silica and the exchange capacity of the residue determined. In another experiment 10 grams of soil were first treated with 1.0 N, 7.0 N, and 8.75 N acid as previously described. After filtering and washing, the residues were transferred to 500-cc Erlenmeyer flasks, 200 cc of 0.5 N sodium hydroxide added, and the suspension brought to a boil. Four grams of sodium chloride were added, the suspension quickly cooled, and filtered. The exchange capacities of the soil residues were determined. Silica was determined in the filtrate. The results are given in Table 4, except for 8.75 N acid which are not given because they are the same as those for 7.0 N acid.

Digestion with 0.5 N sodium hydroxide, not preceded by acid digestion, brought some silica into solution, but had very little effect upon the exchange capacity of the residue. However, the alkali treatment of the residue from the acid digestion still further reduced the exchange capacity of most soils. The decrease averaged 9% of the original exchange capacity of soils previously treated with 1.0 N acid and 13% of the capacity of the soils treated previously with 7.0 N acid. If the exchange capacity of the residue is placed at 100, the so-

TABLE 4.—*Soluble silica and reduction of exchange capacity caused by* 0.5 N *sodium hydroxide.*

Laboratory No.	Soluble silica			Reduction of exchange capacity due to NaOH				
	Alone, M.E.	After 1.0N acid, M.E.	After 7.0N acid, M.E.	Original soil = 100			Residue from acid = 100	
				None, %	1.0N acid, %	7.0N acid, %	1.0N acid, %	7.0N acid, %
25887......	108	505	750	2	14	18	28	64
31321......	174	554	880	0	14	15	26	65
29438......	109	307	860	0	16	6	27	38
31327......	200	727	1,230	0	25	13	38	68
29427......	89	408	930	2	2	16	4	59
23950......	72	344	1,060	2	0	11	0	55
23952......	61	435	1,130	2	0	10	0	59
26089......	68	502	1,220	1	4	14	8	64
23946......	64	498	1,540	2	7	18	22	78
26085......	110	602	1,170	2	7	13	28	72
26823......	90	690	1,300	1	11	17	24	77
26079......	78	738	1,400	0	5	11	8	73
Average....	102	526	1,123	1	9	13	18	64

dium hydroxide removed on an average 18% of the exchange capacity of the residue after 1.0 N acid and 64% of that remaining after the 7.0 N acid. The individual soils varied considerably from the average, especially when the original base-exchange capacity was used as a standard. The alkali digestion caused a reduction of 25% of the remaining exchange capacity of No. 31327 (after digestion with 1.0 N acid) and no reduction of that of Nos. 23950 and 23952. The effect of the alkali on the residue from digestion with 7.0 N acid was practically the same for all soils when the exchange capacity of the residue was 100. Apparently the strong 7.0 N acid decomposed the alumino-silicates to a greater extent than the 1.0 N acid.

The average quantities of silica dissolved by the alkali after treatment with 1.0 N and 7.0 N were 526 and 1,123 M. E., respectively. Evidently there was a considerable change in the nature of the silicate compounds or a greater production of silicic acid with an increase in the strength of acid used for the initial digestion. This is evident still further by a comparison of the quantity of destruction of the exchange capacity due to the alkali treatment. The alkali following the 1.0 N acid caused a further average decrease of only 2.4 M. E. of exchange capacity, although a considerable quantity of relatively unstable exchange complex was still left in the soil, as evidenced by the increased quantity destroyed by 1.75 N acid. After the digestion with 7.0 N acid, when comparatively small quantities of exchange capacity remained in the soil, which was not decreased by the treatment with 8.75 N acid, the alkali caused an average decrease of 4.3 M. E. of exchange capacity, or nearly twice as much as that caused by the same alkali treatment following the 1.0 N acid.

With the 1.0 N acid, the ratio of mols of silica made soluble in the alkali to mols of alumina soluble in the acid was 5 : 1, while the ratio of the increases of soluble silica to alumina was about 3 : 1 when the strength of acid was increased from 1.0 N to 7.0 N. This shows that the silica-alumina ratio of the exchange complex may vary significantly at different stages of decomposition.

EFFECT OF ACID DIGESTION ON MINERALS WHICH MAY OCCUR IN THE SOIL

The base-exchange capacity of soils has been held by Kerr (10, 11), Kelly and his coworkers (8, 9), and others to reside wholly or chiefly in bentonite. In order to determine whether the action of acid digestion on soils were similar to the action on certain soil minerals, five samples of minerals were treated in the same way as were the soils previously discussed. These included a sample of montmorillonite bentonite and one of Ordovician bentonite from Dr. C. S. Ross of the U. S. Geological Survey, a sample of dickite from the United States National Museum, and samples of kaolin from the Heil Corporation and from Eimer and Amend. Their respective total exchange capacities were 84.2, 29.4, 0.54, 4.34, and 3.68 M. E. per 100 grams. The destruction of the exchange complex of the minerals was not nearly so great as was that of the soils under similar treatment. The average destruction of the exchange capacity of the 12 soils by digestion with 1.75 N acid was 64%, while the corresponding decrease for the montmorillonite bentonite was 10% and for the Ordovician bentonite only 6%. The dickite and kaolin showed practically no decrease whatever. The quantity of aluminum dissolved by the 1.75 N acid from the montmorillonite bentonite was equivalent to 371 M. E. The ratio of M. E. of alumina to M. E. of exchange complex destroyed was 43.2, while for soils the corresponding average figure was 16.4. It seems probable, then, that either the bentonite of soils is sufficiently weathered so that the exchange complex breaks down in the soil much more readily than when the bentonite occurs in larger deposits, or a considerable part of the exchange capacity of soils is due to other minerals which are decomposed by acids much more easily than bentonite.

Further evidence that bentonite behaves differently from the soil is found in the work of Kerr (10), who found that a sample of bentonite with an exchange capacity of 97.7 M. E. had 66 M. E. exchange capacity after 6 hours digestion with boiling 0.2 N hydrochloric acid and extraction of the silica with sodium carbonate. He found that the exchange capacities of two samples of bentonite were completely destroyed by 12 hours boiling with normal hydrochloric acid and extraction with sodium carbonate. On an average, only 85% of the exchange capacity of the soils here studied were destroyed by a similar treatment. This indicates that minerals other than those contained in bentonite similar to that studied are responsible for at least a part of the base exchange capacity of soils.

DISCUSSION

The results reported indicate the presence of a series of aluminosilicic acids in the base exchange complex, varying in quantity, relative proportions, and activity in the different soils. Bradfield (2, 3, 4) suggested the presence of a series of similar acids in the exchange complex. His explanation for obtaining a typical monobasic acid titration curve for his colloids is that a mixture of acids with unlike dissociation constants may give a monobasic curve if their respective constants are close enough together so that their individual curves overlap. Varying proportions of the different acids would probably give slightly different curves. The work of Fraps and Fudge (6), Pierre and Scarseth (14), and others shows differences in the exchange complexes of different soils which can best be explained on the basis of such a series of acids. Fudge (7) has recently shown that there are significant differences in the quantities of potassium and ammonium fixed from dilute solutions per unit of exchange capacity of different soils. The work reported here indicates the presence of compounds comparatively unstable to acids in some soils, and their absence in others. Soils Nos. 29438 and 29427 in particular show the presence of such compounds. Under the influence of comparatively weak acids, the exchange capacity of these soils is considerably reduced with solution of a comparatively small amount of alumina. This indicates the presence of relatively unstable, easily decomposable compounds. Other soils, for example, Nos. 25887 and 31321, do not contain such compounds. The exchange complexes of these soils are apparently much more uniform and are probably composed of fewer exchange acids. It is interesting to note that after the comparatively unstable compounds have been decomposed, all of the soils tend to have similar ratios between decrease of the remaining exchange capacity and soluble aluminum.

The evidence here discussed offers only indications, since the acid no doubt dissolves other alumina besides that in the exchange complex, and the exchange compounds may be decomposed by the acid with a partial solution of the alumina and the formation of compounds containing lower percentages of alumina.

Exchange compounds containing silica which is soluble in 0.5 N sodium hydroxide are formed only after considerable quantities of alumina have been removed from the original exchange compounds by acid digestion. The average amount of silica rendered soluble in alkali by 7.0 N acid was equivalent to 282 millimols per 100 grams of soil, while the average amount of alumina removed from the soils was but 81 millimols.

SUMMARY

The coefficient of correlation between the total exchange capacities of 259 soils and the percentages of iron and aluminum oxides soluble in hydrochloric acid of 1.115 sp. gr. was $+ .878 \pm .010$.

Digestion in boiling water for 10 hours with 0.2, 1.0, 1.75, 3.50, 7.00, and 8.75 N hydrochloric acid reduced the average total exchange capacities of 12 soils 17, 47, 64, 74, 80, and 80%, respectively.

When the alumina dissolved by the 7.0 N acid was placed at 80, the relative quantities of alumina dissolved were 10, 30, 58, 76, 84, and 80%. The correlation coefficient between the loss of exchange capacity and the quantity of alumina dissolved by the various strengths of acids was .859 ± .029. The average decreases in M. E. of total exchange capacity expressed as percentages of M. E. of soluble alumina were 10.0, 9.2, 6.0, 5.4, 5.3, and 5.5.

No relation was apparent between decrease in total exchange capacity and the ferric oxide dissolved.

The ratio of decrease in total exchange capacity to alumina dissolved varied with individual soils, especially with 0.2 N and 1.0 N hydrochloric acid. With stronger acids, the relation between decreased total exchange capacity and soluble alumina was fairly constant.

When the quantity of alumina soluble in the various acids is expressed as M. E., the decrease in total exchange capacity was about 10% of the alumina dissolved with dilute acids but only 5.4% with the stronger acids. This indicates a difference in the nature of the compounds of the exchange complex acted upon by the different strengths of acid.

Digestion with 0.5 N sodium hydroxide of the original soil and the residues from 1.0 N and 7.0 N hydrochloric acid still further decreased the exchange capacity 1, 9, and 13% of the original capacity, or 0.3, 2.4, and 4.3 M. E., respectively. Silica in the sodium hydroxide extract amounted to 102, 526, and 1,123 M. E. The relation between the silica dissolved and decrease in exchange capacity was very small.

The exchange capacities of two samples of bentonite digested with acid were destroyed to a much smaller degree than were those of soils receiving similar acid treatment. Minerals other than bentonite appear to be responsible for a considerable proportion of the exchange complex of soils.

The exchange capacities of a sample of dickite and two of kaolin were not affected by acid digestion.

The results indicate the presence of a series of aluminosilicic acids in the exchange complex, varying in different soils with respect to strength, stability, and relative proportions.

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STUDIES OF THE INHERITANCE OF AND THE RELATIONSHIPS BETWEEN KERNEL TEXTURE, GRAIN YIELD, AND TILLER-SURVIVAL IN CROSSES BETWEEN REWARD AND MILTURUM SPRING WHEATS[1]

O. S. Aamodt, J. H. Torrie, and A. Wilson[2]

Hard kernel texture in bread wheats is generally associated with high protein content, and with high milling and baking qualities. The opinion is held that the texture of the kernels is determined almost entirely by the climatic conditions under which the wheat is grown. Recent investigations (1, 2, 3)[3] at the University of Alberta, Edmonton, Canada, have indicated that soil and heredity play a much greater part in influencing the bread-making qualities of wheat than has generally been accepted. Intensive studies are being made on the influence of black and gray soils on the kernel texture, protein content, and baking qualities of several wheat varieties (1,2). The mode of inheritance of kernel texture, protein content and baking quality in several wheat crosses is also being studied under the same conditions (3).

Bryan and Pressley (7) have recently called attention to the possible connection between texture of kernels and tillering in Early Baart wheat. As one phase of the general studies mentioned above, the writers of the present paper were interested in determining the interrelationships existing in the number of tillers per plant, grain yield, and texture of kernels in segregating populations from crosses between Reward and Milturum spring wheats.

MATERIALS AND METHODS

MATERIALS

Eight entire F_2 populations and 100 F_3 lines of Reward X Milturum were used in the present study. Reward, C. A. N. 1509,[4] is a hard red spring wheat originating from a Marquis X Prelude cross, at the Central Experimental Farm, Ottawa. It is fair in yielding ability, possesses exceptionally good baking quality, and produces a kernel of vitreous texture even when grown on the gray wooded (Fallis, Alberta) soil (podsol). Milturum 0.321, C. A. N. 1415, is a soft red spring wheat obtained in 1928 from Dr. Talanov of the West Siberian Experimental Station, U. S. S. R. It is high in yielding ability, possesses poor baking quality, and produces a kernel of starchy texture even when grown on the black (Edmonton) soil (chernozen).

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[3]Reference by number is to "Literature Cited", p. 465.

[4]C. A. N. = Canadian Accession Number.

EXPERIMENTAL METHODS

The crosses between Reward and Milturum were made at the University of Alberta, Edmonton, Canada, in 1929. The F_1 plants were grown in the field in 1930. There was no indication of sterility in any of the crosses.

A number of the F_2 populations were grown at Edmonton, Alberta, in 1932. Eight F_2 populations and 100 selected F_3 lines were grown at Fallis, Alberta, in 1933. The selection of the F_3 lines was based on the kernel texture of the F_2 plants grown at Edmonton in 1932. Of these plants, four groups of 25 each were used. The kernel texture of the respective groups were completely vitreous, vitreous with a trace of starchiness, starchy with a trace of vitreousness, and completely starchy.

The material was grown in 5-foot rows, 1 foot apart, with 25 spaced seeds per row. Parental replications were made every 30 rows. Each plant was harvested and threshed individually. The number of culms per plant was recorded at harvest. The data obtained from the classification of the material for the various characters for each F_2 population originating from a different F_1 plant were recorded separately and combined only after it was ascertained that there was no significant difference between the different populations. The significance of the correlation coefficients was determined by the method suggested by Fisher (17).

INHERITANCE OF KERNEL TEXTURE

Considerable controversy exists in regard to the relative weight that should be attached to the several factors influencing the kernel texture of wheat. The opinion is held that the kernel texture of wheat is determined primarily by the climatic conditions under which it is grown. Genetic studies have shown definitely that there exists inherent differences for kernel texture among the different wheat varieties. Recent investigations (2, 3) at the University of Alberta, have shown that a very satisfactory method of studying the inherent differences in kernel texture between wheat varieties is to use material grown under a special environment in regard to soil and climate.

The environmental conditions at Edmonton usually are such that wheat varieties grown there differ little in kernel texture, with the exception of those varieties which possess very poor quality, like Milturum. However, in 1932, due both to climatic conditions and to the great difference in the kernel texture of the parents, a good differentiation for this character was obtained at Edmonton. In order to avoid this uncertainty of obtaining a differentiation at Edmonton, texture studies are conducted at Fallis, Alberta, 50 miles west of Edmonton, in the gray wooded soil (podsol) area. In this district the soil and climatic conditions are such as to result in a good differentiation for kernel texture of wheat every year. A description of the soil of this area is given by Wyatt and Newton (30).

A complete review of the literature on kernel texture of wheat is reported by Aamodt and Torrie (2, 3). The number of factor pairs found to govern the mode of inheritance of kernel texture by the different investigators is as follows: Biffen (4) and Bryan and Pressley (6, 7), one factor pair; Engledow and Hutchinson (16) and Freeman (19), two factor pairs; and Harrington (21) and Clark, Florell, and Hooker (11), several factor pairs. Aamodt and Torrie (3), in crosses

between Selection I–28–60 X Milturum 0.321, found that certain F_2 populations indicated a partial dominance of vitreous texture by two main factor pairs, others by one main factor pair; while in still a third group starchy texture was partially dominant by one main factor pair. The presence of minor modifying factors, influencing the expression of the main factor pairs, was reported by both Aamodt and Torrie (3) and Bryan and Pressley (7).

EXPERIMENTAL RESULTS

The inheritance of kernel texture was studied in the F_1 and F_2 grown at Edmonton in 1930 and 1932, respectively, and in the F_2 and F_3 grown at Fallis in 1933. In every instance a good differentiation for kernel texture was obtained. The material was classified for this character by assigning values from 1 to 10, "1" being completely starchy and "10" completely vitreous.

The texture of the seed from the F_1 plants was completely starchy, indicating a complete dominance of the starchy endosperm. The four groups of selected F_2 plants of Reward X Milturum were also classified for kernel texture as described previously. The distribution, mean, and standard deviation for kernel texture, as shown by data in Table 1, are essentially similar for both generations of hybrids. The correlation coefficient between the F_2 and F_3 kernel texture was +0.749 (P value <0.01), which clearly indicates the heritable nature of kernel texture.

TABLE 1.—*Frequency distribution, mean, and standard deviation for kernel texture index of Reward x Milturum selected plants grown at Edmonton in 1932 and the corresponding F_3 and parental lines grown at Fallis in 1933.*

Cross or parent*	Classes for kernel texture										Total number	Mean kernel texture	Standard deviation
	1	2	3	4	5	6	7	8	9	10			
					1932								
F_2 Edmonton	3	16	17	6	6	12	12	10	9	5	96	5.3±0.27	2.7±0.19
					1933								
P_3 Reward	—	—	—	—	—	—	—	—	2	4	6	9.7±0.21	0.4±0.14
P_3 Milturum	2	4	—	—	—	—	—	—	—	—	6	1.7±0.21	0.4±0.14
F_3 Fallis	—	7	16	17	24	14	12	2	4	—	96	4.9±0.18	1.7±0.12

*The kernel texture of the P_3 parents was Milturum 1 and Reward 10.

The difference between the mean kernel texture index of any of the F_2 populations grown at Fallis in 1933, and that of the one with the mean closest to it was not significant. A significant difference of 1.3±0.29 was obtained between the F_2 populations having the highest and lowest mean value for texture index. The slight variability found in the means of the several F_2 populations is probably due to the presence of minor modifying factors. Since these differences are not very great, the data obtained from the several F_2 populations are treated collectively and are given in Table 2.

TABLE 2.—*Frequency of distribution, mean, and standard deviation for kernel texture of Reward x Milturum F_2 populations treated collectively and for parental plants grown at Fallis in 1933.*

Parent or cross	Classes for kernel texture										Total number	Mean kernel texture	Standard deviation
	1	2	3	4	5	6	7	8	9	10			
Reward....	—	—	—	—	—	—	2	2	18	52	74	9.6±0.08	0.6±0.05
Milturum..	28	56	8	—	—	—	—	—	—	—	92	1.8±0.06	0.6±0.05
F_2.........	43	92	103	112	148	127	79	79	63	18	864	5.1±0.08	2.3±0.06

The variability of the hybrids is significantly greater that that of either parent, clearly indicating that segregation has occurred. The distribution of the hybrids approaches that of a normal curve, which suggests that the inheritance of kernel texture, in these crosses is governed by polymeric (multiple) factors.

The heritable nature of kernel texture, as shown by the data reported herein, is in agreement with the conclusions obtained by other investigators studying the inheritance of this character in wheat crosses. The lack of agreement in the factorial explanations obtained by the several workers is to be expected, owing to the different varieties used as parents and the conditions under which the material was grown.

INHERITANCE OF GRAIN YIELD

Clark (10) states that, "Yield may be considered as a character complex affected by environment and by most of the morphological and physiological characters of the plant." Inheritance studies on grain yield in spring wheat crosses have been made by a number of investigators (10, 11, 12, 13, 14, 15, 27, 28). The results obtained by Clark and his co-workers (11, 12) show the great influence that different environmental conditions have upon grain yield. Transgressive segregation for the inheritance of grain yield was reported by several investigators (11, 12, 14, 28). A partial dominance of the high-yielding parent was obtained by several workers (10, 14, 15). Torrie (27), from the study of the F_3 of Reward X Caesium, reports that the inheritance of grain yield appeared to be governed by a number of polymeric factors, with a partial dominance of the low yield of Reward.

EXPERIMENTAL RESULTS

The individual plant yield of grain in grams was determined for the eight F_2 populations and the parents of Reward X Milturum grown at Fallis in 1933. The average grain yield and standard deviation for each F_2 population and the parents were calculated. The data are given in Table 3.

The data in Table 3 show that the differences between the several F_2 populations are not significant, with the exception of F_2 population 2005. No satisfactory explanation for the low yield of the F_2 population 2005 can be offered. Because its average yield differs signifi-

TABLE 3.—*Mean and standard deviation for grain yield in grams of Reward x Milturum F_2 populations and parental plants grown at Fallis in 1933.*

Parent or F_2 population	Number of plants	Mean grain yield	Standard deviation
Reward. .	75	4.2±0.27	2.5±0.21
Milturum	91	7.0±0.38	3.7±0.27
1999	118	4 6±0.27	2.9±0.16
2000.	156	4.8±0.22	2.8±0.19
2001	14	4.9±0.80	3 5±0.64
2002	106	4.6±0.25	2.5±0.18
2003.	92	4.4±0.30	2.7±0 21
2004	114	4 5±0 22	2 4±0.15
2005	127	3.3±0.18*	1.9±0.12
2006	137	4 7±0.18	2.1±0.13
Total and averages for the F_2	737	4 6±0 09	2 6±0.06

*Not included in average.

cantly from those of the other F_2 populations, it is not included in the average. The difference in the grain yield between Reward and Milturum of 2 8±0 48 grams is evidently very significant. The variability of grain yield of Reward, as measured by the standard deviation, and the average of the F_2 populations are practically the same, while that of Milturum is significantly higher The average yield of the F_2 populations tends to that of the low-yielding parent Reward, which suggests a dominance of low yield.

It is very difficult to arrive at any satisfactory factorial explanation of grain yield, particularly in an F_2 population, where the yield is based entirely upon individual plants This difficulty is due largely to the varying effect of environmental factors on the grain yield of the individual plants in an F_2 population Torrie (27) has shown that the average plant yield of an F_3 row gives a much better indication of the yielding ability of a line than that of an individual F_2 plant. Although no satisfactory genetic explanation can be offered for the inheritance of grain yield, the results are in agreement with those of other workers in showing the complex nature of the mode of inheritance for this character.

INHERITANCE OF NUMBER OF MATURE CULMS

Grantham (20) reports that the capacity for tillering, in winter wheat is a varietal characteristic Stewart (26) found no segregation for the number of culms in crosses between Dicklow and Sevier. Helgendorf (22) found differences both in the number of tillers produced and the tiller survival among a number of wheat varieties grown in New Zealand. Bridgford and Hayes (5), from a study of factors affecting yield in hard red spring wheat, report that in the number of heads per row, which is a measure of tillering ability, the N. D. 1656 selections and other Kota-Marquis crosses were relatively low, whereas Hope, Marquillo, H_{44}, and most of the double crosses excelled in this respect Clark and Wilson (8) found no genetic differences in the tillering rates of 24 varieties of durum spring wheats.

EXPERIMENTAL RESULTS

The number of tillers which produced mature heads (tiller survival) was counted at harvest for both the F_2 and the F_3 of Reward X Milturum grown at Fallis. In Table 4 are presented data which give the mean and standard deviation of Reward X Milturum F_2 populations and parental plants for tiller survival.

TABLE 4.—*The mean and standard deviation for tiller survival of Reward x Milturum F_2 populations and parental plants grown at Fallis in 1933.*

Parent or F_2 population	Number of plants	Mean tiller survival	Standard deviation
Reward	75	6.3±0.31	2.6±0.6
Milturum	91	7.2±0.18	3.3±0.11
1999	118	6.9±0.25	2.8±0.15
2000	156	6.4±0.22	2.7±0.18
2001	14	6.2±0.89	3.4±0.64
2002	106	6.5±0.27	2.9±0.19
2003	92	6.2±0.25	2.4±0.18
2004	114	5.5±0.19	2.0±0.13
2005	127	5.2±0.16	1.8±0.12
2006	137	5.1±0.18	2.1±0.12
Total and averages for the F_2	864	6.0±0.09	2.6±0.06

The difference in the mean tiller survival of any F_2 population and the one with its mean closest to it is not significant. However, the difference in tiller survival of 1.8±0.31 between the high F_2 population 1999 and the low F_2 population 2006 is significant. Soil heterogeneity rather than genetic factors are believed to have resulted in the significant differences between these two F_2 populations. This is borne out by the data in Table 4 which show a progressive decrease in the average tiller survival per F_2 population from F_2 population 1999 to 2006. The material was grown in the field in the same order as presented in Table 4. The difference between the parents of 0.90±0.37 tillers is barely significant. The mean of all the F_2 populations is slightly less than that of Reward, the low parent. The variability of the F_2 populations is less than that of either parent.

The data in Table 5 are based on the average tiller survival of Reward X Milturum F_3 lines and parental rows grown at Fallis in 1933. The differences in both the mean and standard deviation between the parents and hybrids are not significant.

TABLE 5.—*Frequency distribution, mean, and standard deviation for tiller survival of Reward x Milturum F_3 lines and parental rows grown at Fallis in 1933.*

Parent or cross	Classes for tiller survival									Total number	Mean tiller survival	Standard deviation
	4	5	6	7	8	9	10	11	12			
Reward	1	—	2	1	2	—	—	—	0	6	6.5±0.57	1.4±0.41
Milturum	—	1	1	2	—	2	—	—	—	6	7.2±0.60	1.5±0.45
F_3 lines	2	13	14	35	19	12	—	1	1	97	7.1±0.15	1.4±0.11

Both the F_2 and F_3 data show, that for the conditions of the experiment, there is no genetical difference in the tiller survival of Reward and Milturum.

ASSOCIATIONS AMONG CHARACTERS STUDIED

It is very important in a plant breeding study to have a knowledge of the relationships existing among or between each pair of characters. Selection may be greatly facilitated if it is shown that a readily classifiable character is linked with a complex character. Such studies also indicate the extent to which the various desirable characters of each parent are associated with each other and the possibilities of obtaining suitable recombinations in the hybrids. The various relationships existing among tiller survival, grain yield, and kernel texture are shown by the simple and first order partial correlation coefficients given in Table 6.

TABLE 6.—*Simple and first order partial correlation coefficient between kernel texture, grain yield, and tiller survival for the F_2 and between kernel texture and tiller survival for the F_3 of Reward x Milturum grown at Fallis in 1933.*

Number of samples	Generation	Simple correlations		Partial correlations	
		Variables correlated*	r	Variables correlated	r
737.......	F_2	TY	+0.078	TY.S	—0.066
737.......	F_2	SY	+0.780†	SY.T	+0.784†
737.......	F_2	TS	+0.152†	TS.Y	+0.146†
98.......	F_3	TS	+0.279†	——	——

*T = kernel texture; Y = grain yield; S = tiller survival.
†P value exceeds the 1% point.

KERNEL TEXTURE AND GRAIN YIELD

Freeman (18) studied the relative yielding ability of hard- and soft-textured wheat grown in mechanical mixtures. He found with Turkey wheat a negative correlation, while with durum wheats he obtained a positive correlation between grain yield and hard texture. Bryan and Pressley (7) studied the yielding ability of a number of hard and soft texture strains of Baart wheat. They found that the soft strains yielded the highest. This, they state, explains the progressive increase in the percentage of soft kernels found over a 6-year period in mechanical mixtures of soft- and hard-textured strains.

The simple correlation coefficient between kernel texture and grain yield for the F_2 of Reward X Milturum grown at Fallis was +0.078. By the use of the partial correlation coefficient in which tiller survival was held constant, a correlation of —0.066 was obtained. These correlations have a P value greater than 0.05 and consequently indicate that there is no relationship between kernel texture and grain yield. The results indicate that there should be no trouble in securing vitreous texture lines from the material studied for Fallis conditions without suffering a loss in yield. The disagreement be-

tween the conclusions of this investigation and those of other workers (7, 18) is probably due to differences both in the material used and in the environmental conditions under which it was grown.

TILLER SURVIVAL AND GRAIN YIELD

Clark (9) reports a positive correlation between the extent of tillering and the grain yield of barley. Grantham (20) found for winter wheat that increased yield is associated with an increase in the number of tillers up to four or five. Smith (24) found no close relationship to exist between the extent of tillering and grain yield from a study of rod row trials of wheat, oats, and barley. He cites the work of Love and Leighty with oats and Vestergaard with barley, both of whom report a positive correlation between tillering and yield. He also cites the work of Buffum, Schribaux, Gericke, Leschenko, and Opeta, all of whom record disadvantages with too much tillering. Sprague (25) and Quisenberry (23) both found that the number of heads per unit area was one of the most important factors in determining grain yield. Bridgford and Hayes (5) obtained a positive but non-significant correlation between grain yield and number of spikes per row from rod row trials of spring wheat. In this study, two main groups of strains were included, the Minnesota double crosses, which excelled in heads per row, and the Kota crosses, which lacked stooling ability. Since certain strains of both groups excelled in yield, the correlation between yield and heads per row was not significant. Waldron (29) obtained a partial correlation of +0.933 between spikes per row and grain yield, holding grains per spike constant, from which he concludes that, with respect to yield, these two components form nearly or quite a closed system.

The simple correlation coefficient between grain yield and tiller survival for the F_2 populations of Reward X Milturum grown at Fallis was +0.780. Holding grain texture constant, the partial correlation was +0.784. These correlations indicate that, under the conditions of the experiment, there exists a definite relationship between grain yield and tiller survival.

KERNEL TEXTURE AND TILLER SURVIVAL

Bryan and Pressley (7) grew soft and hard strains of Baart wheat spaced 3 inches each way. From their data they concluded that the soft strains not only produced more heads per plant with close spacing than the hard strains, but as the amount of space per plant increases the difference in the number of heads per plant increases proportionately.

The relationship between kernel texture and tiller survival was studied in the F_2 and F_3 of Reward X Milturum grown at Fallis. The simple correlation coefficients between grain texture and tiller survival for the F_2 populations and F_3 lines were +0.152 and +0.279, respectively. In the F_2, holding grain yield constant, the first order partial correlation was +0.146. These correlations are statistically significant and indicate a slight tendency for the plants possessing kernels of vitreous texture to have a higher tiller survival than those with starchy texture.

In Table 7 the data show the average tiller survival for the different texture classes of Reward X Milturum F_2 populations and F_3 lines grown at Fallis in 1933.

TABLE 7.—*Average tiller survival for the different texture indices of the F_2 plants and the F_3 lines of Reward x Milturum grown at Fallis in 1933.*

Texture index	Tiller survival			
	F_2		F_3	
	Number of plants	Mean	Number of lines	Mean
1	43	5.9±0.28	—	—
2	92	6.1±0.18	7	6.3±0.34
3	103	6.2±0.24	16	7.2±0.44
4	112	5.9±0.21	17	6.5±0.29
5	148	6.5±0.25	24	6.8±0.24
6	127	6.9±0.24	15	7.8±0.30
7	79	7.1±0.27	12	6.9±0.25
8	79	6.9±0.34	2	8.0±0.72
9	63	7.3±0.43	4	8.8±0.66
10	18	6.6±1.08	—	—
Total and average for the F_2 and F_3	864	6.0±0.09	96	7.1±0.15

The results show a more or less progressive tendency for increased vitreousness of kernel texture in the sample to be associated with an increase in tiller survival. These data support the evidence obtained from the correlation studies between kernel texture and tiller survival that the F_2 plants and F_3 lines producing kernels of vitreous texture tend to have a higher tiller survival than the F_2 plants and F_3 lines with kernels of starchy texture. The results of this investigation are in disagreement with those obtained by Bryan and Pressley (7). This is probably due both to the different material used and to the different environmental conditions under which the experiment was conducted.

SUMMARY

Crosses between Reward and Milturum were studied genetically for the inheritance of and the relationship between the characters of kernel texture, grain yield, and tiller survival. Part of the F_2 populations and selected F_3 lines were grown at Fallis, Alberta, in order to secure a satisfactory differentiation for kernel texture.

The inheritance of kernel texture appeared to be explainable on the assumption of polymeric factors. Starchy texture was dominant to vitreous texture.

The inheritance of grain yield appeared to be of a complex nature. A partial dominance of low yielding factors was indicated.

No genetic difference was obtained in the tiller survival of Reward and Milturum grown at Fallis.

No genetic relationship was found between grain yield and kernel texture.

A highly significant positive correlation was obtained between grain yield and tiller survival.

A small but significant association was obtained between vitreous kernel texture and high tiller survival.

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THE INFLUENCE OF LOW TEMPERATURE ON SEEDLING DEVELOPMENT IN TWO INBRED LINES OF CORN[1]

OLIVER F. SMITH[2]

THE growth and development of corn seedlings at low temperatures is primarily dependent upon their ability to develop chlorophyll, the efficiency with which they utilize their endosperm reserves, and their ability to build tissues which resist the attack of seedling blight organisms. Observations have shown that seedlings of inbred lines of corn respond differently when grown at low temperatures. Some are able to synthesize chlorophyll, make an efficient use of their endosperm reserves, and develop tissues which resist the attack of soil-borne parasites, while others do not develop chlorophyll, make an inefficient use of their endosperm reserves, and are susceptible to the attack of soil-borne parasites.

Owing to the need of extending the growing season for corn in the northern portion of the United States, corn is planted early, which often subjects it to low temperatures during the early seedling stages of development. For this reason it seemed desirable to study differences in the reactions of seedlings, to determine convenient methods of measuring and evaluating seedling response to low temperatures, and ultimately to correlate these responses with later development both in the inbreds and in the hybrid combination.

METHODS AND MATERIALS

The inbreds RYD_4 and GG_{26} produced at the Wisconsin Experiment Station and inbred for 10 years were chosen for this study because of their marked contrast in response to low temperature. RYD_4 shows a more stable type of development with the formation of chlorophyll at the lower temperatures (17°C), whereas GG_{26} is less stable in its reaction and is chlorotic at a temperature of 17°C. Both inbreds are green when grown at a temperature of 24°C. All results reported here are from experiments with these two inbreds and subsequent generations produced by selfing or hybridizing these lines.

Unless otherwise stated, the seedlings were grown in the greenhouse during the winter. The greenhouses were maintained at temperatures of 17° and 24°C, with an average fluctuation in temperature of about 2 degrees above and below the desired temperatures.

The houses will be referred to in the discussion as the 24° and the 17°C houses, respectively. When it was necessary to change the temperature at which a given lot of seedlings was growing, the plants were moved to the house which was being held at the desired temperature.

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TEMPERATURE AND PIGMENT FORMATION

The difference in the ability of these inbred lines of corn to form chlorophyll at low temperatures was very striking, especially at 16° to 19°C. When grown at this temperature range the seedlings of GG_{26} were typically of the virescent type. The young plants were practically without chlorophyll except at the extreme tips of the leaves where chlorophyll sometimes developed in small amounts. Later during the course of their development, these seedlings gradually developed a slight yellowish color. There was, however, considerable range in pigment formation among the individuals in a given population. Some were nearly pure white with only a faint suggestion of yellow or green color at the leaf tips, while others were a light yellow to greenish yellow rather than yellowish white in color. A given population usually represented all gradations between these limits. In contrast, the seedlings of RYD_4, grown at the same temperature, showed normal pigment development. The differences in pigment formation shown by these two seedling types were so marked that it seemed to warrant further investigations, especially on the effect of low temperatures on the formation of chlorophyll and other associated pigments and their relation to seedling metabolism and growth.

QUANTITATIVE DETERMINATIONS OF CHLOROPHYLL AND CAROTINOID PIGMENTS

It is well known that accompanying chlorophyll are two yellowish pigments, carotin and xanthophyll, which are known as the carotinoids. (A third pigment, fucoxanthin, occurs in brown algae.) Little is known regarding the formation of these pigments by the plants and their relation to each other. Results of other workers (7, 8, and 11)[3] suggest, however, that a close correlation exists between the formation of chlorophyll and at least one of the carotinoid pigments. The purpose of these experiments was to determine to what extent the formation of the carotinoid pigments in these corn seedlings is affected by low temperature, especially in relation to chlorophyll development.

Pigment extractions were made from fresh plant tissue according to the method outlined by Schertz (13). All extractions were made from leaf blade tissue of seedlings which had developed to the third leaf stage. Some difficulty was encountered in separating the carotin and xanthophyll until the method was modified to include further extracting with methyl alcohol and petroleum ether after the original separation of these pigments had been made. Quantitative determinations were made by means of a colorimeter, using malachite green, orange G, and martius yellow for standards, in the proportions suggested by Sprague (14).

Extractions were made in duplicate from seedlings grown at temperatures of 24° and 17°C. From four to six readings were made on the colorimeter for each extraction. It was difficult, however, to get these readings to check closely. The figures given represent the average of these readings and are to be considered as relative rather than absolute. The results are shown in Table 1.

[3]Figures in parenthesis refer to "Literature Cited", p. 470.

TABLE 1.—*Quantitative determinations of chlorophyll and carotinoid pigments in seedlings of RYD_4 and GG_{26} grown in the greenhouse during the winter.*

Pigment content (mgs) in 10 grams fresh tissue					
Chlorophyll		Carotin		Xanthophyll	
RYD_4	GG_{26}	RYD_4	GG_{26}	RYD_4	GG_{26}
At 24°C					
29.2	15.4	0.4	0.3	0.5	0.4
28.3	16.6	0.4	0.2	0.4	0.5
At 17°C					
29.9	Trace	0.5	Trace	0.4	0.5
30.6	Trace	0.5	Trace	0.5	0.4

The most significant point brought out by these data is the close parallel between chlorophyll and carotin formation. The extractions of the pigments from the seedlings of GG_{26} grown at 17°C showed only a trace of green pigments and of carotin, whereas the xanthophyll content remained as high at 17° as at 24°C. It will also be noted that chlorophyll pigmentation and also carotin formation was less in GG_{26} at 24°C than in RYD_4. The chlorophyll and carotin content of seedlings of RYD_4 was approximately the same at 17° as at 24°C. It is suggested that the parallel relationship shown between chlorophyll and carotin formation may be due to both these pigments being dependent upon the reaction of the same gene or gene complex for their expression or due to different genes which react alike under these environmental conditions. There is also the possibility of a chemical relationship between the chlorophyll and carotin molecules or their precursors.

FIELD EXPERIMENTS ON RELATION OF TEMPERATURE TO CHLOROPHYLL FORMATION

Seedlings of GG_{26} grown in the field at low temperatures show the virescent character. This was shown by field experiments in the spring of 1932 and the fall of 1933. In the spring of 1932 a planting of several inbred lines of corn, including GG_{26} and RYD_4, was made on April 18, which is about 1 month earlier than the usual planting date at Madison. Both lines reached the third leaf stage about May 12. During this period from May 2 to May 12, the air temperature during the day ranged from 23° to 15° with an average temperature of 19.3°C. The night temperature ranged from 12° to 7° with an average temperature of 10.5°C. Growing under these conditions the seedlings of GG_{26} showed the same virescent character as they did in the greenhouse at a temperature range of 16° to 19°C, whereas the seedlings of RYD_4 remained green.

A planting of these seedlings was also made in the field on September 23, 1933, from freshly harvested seed. The plants emerged from the soil about October 2 and had reached the third leaf stage

by October 13 when they were frosted. During this period the air temperature during the day ranged from 21° to 10° with an average temperature of 16°C. The night temperature ranged from 12° to about —3° with an average temperature of 9.2°C. Here again the seedlings of GG_{26} were virescent while those of RYD_4 were green in color. It seems, then, from the behavior of these seedlings, both in the greenhouse and in the field, that temperature is probably the principal environmental factor associated with the expression of the genetic factor complex controlling chlorophyll formation. However, the effect of low light intensity and a shorter period of light exposure evidently modifies the response to temperature.

INHERITANCE OF THE VIRESCENT CHARACTER

These two inbreds and the F_1 and F_2 generations produced from crosses between these lines were grown together in the greenhouse during the months of December and January at a temperature range of 16° to 19°C. Under these conditions the seedlings of GG_{26} and RYD_4 were virescent and green, respectively, the F_1 plants were all green, and the F_2 generation segregated for the green and virescent characters. The segregation was not clear cut, however, as there was a gradation in seedling color from white to normal green. The majority of the seedlings, however, were either definitely green or definitely virescent with a relatively small number representing the intermediate type. These intermediate plants were placed with the green or virescent group according to which group they resembled most. From a total of 1,301 F_2 plants, there were 970 green seedlings and 331 virescent seedlings. This is a close fit to a 3 : 1 ratio and it is therefore considered that this virescent phenotype is probably inherited as a simple Mendelian recessive to normal green. It would be desirable, however, to carry some of this material to the 3rd and 4th generations and to do some back crossing in order to be sure of a correct genetic analysis.

When populations from reciprocal crosses between RYD_4 and GG_{26} were considered separately, there was a higher percentage of virescent seedlings in the cross GG_{26} X RYD_4 than in the reciprocal cross. This situation existed in each of four different series. The results are shown in Table 2.

TABLE 2.—*Numbers and percentages of green and virescent seedlings in F_2 populations of the cross RYD_4 x GG_{26} and the reciprocal cross grown in the greenhouse at a temperature of 16° to 19°C.*

Cross	Number of plants	Number green	Number virescent	Percentage virescent
RYD_4 x GG_{26}	613	500	113	18.4
GG_{26} x RYD_4	688	471	217	31.5
Totals	1,301	971	330	25.3

From the descriptions of virescent seedlings given by Lindstrom (10), Demerec (2), Carver (1), and Phipps (12), it appears that the

type of virescence shown by the seedlings of GG_{26} most nearly corresponds to the virescent type 2 described by Demerec. The virescent seedlings also resemble the description of virescent 19 given by Phipps.

ENDOSPERM UTILIZATION AND TOP GROWTH

During the early seedling stages of development, corn plants are dependent largely on their endosperm reserves for respiration and growth. A rapid utilization of these materials necessitates an early establishment of an efficient photosynthetic activity on the part of the plant. Any condition which materially influences the establishment of this photosynthetic activity will generally influence the total amount and quality of plant tissues produced.

In this phase of the study an attempt has been made to determine the comparative rate of endosperm utilization and the amount of top growth produced during the seedling stages of RYD_4 and GG_{26}. Naturally, various factors of the environment enter into such a study. In these studies temperature has been the changing factor, other conditions having been kept as nearly constant as possible.

Plants were grown and harvested at successive growth stages at constant and at changing temperatures. The first series was removed from the soil at the time the first leaf had just broken through the coleoptile, the second series when the first leaf was completely unfolded and the second leaf was just beginning to unfold, the third series when the first and second leaves were unfolded and the third leaf just beginning to show at the top of the plant, and the fourth series when the first three leaves were unfolded. These growth stages were designated as the coleoptile, first leaf, second leaf, and third leaf stages of development, respectively. Other seedlings were grown to the third leaf stage at a temperature of 24°C then shifted to a temperature of 17°C for 4 and 8 days before being harvested.

Weights of tops and kernel remains were taken after the seedlings had been removed from the soil, washed with water, and the tops separated from the kernel by cutting them off at the cotyledonary node. Dry weights were taken after the plants had come to constant weight in an oven held at 100° to 105°C.

The amount of endosperm utilized by the plants was determined by subtracting the dry weight of the kernel remains from the calculated dry weight of the original kernel. From these figures the percentage decrease in weight of kernels was determined.

ENDOSPERM UTILIZATION AND TOP GROWTH OF SEEDLINGS GROWN AT CONSTANT TEMPERATURES

The results obtained on endosperm utilization and top growth of seedlings grown at constant temperatures are shown in Figs. 1 and 2. The data were obtained on populations of between 400 and 500 plants for each stage of development, represented by four different series.

The results (Fig. 1) show that at a temperature of 24°C the amount of top growth produced is the same for the two inbreds at every stage of development, whereas endosperm utilization is greater for GG_{26} at every stage of development, except at the coleoptile stage. The difference shown at the coleoptile stage is due to a more rapid germination of RYD_4. It is of interest to note further that seedlings of GG_{26}

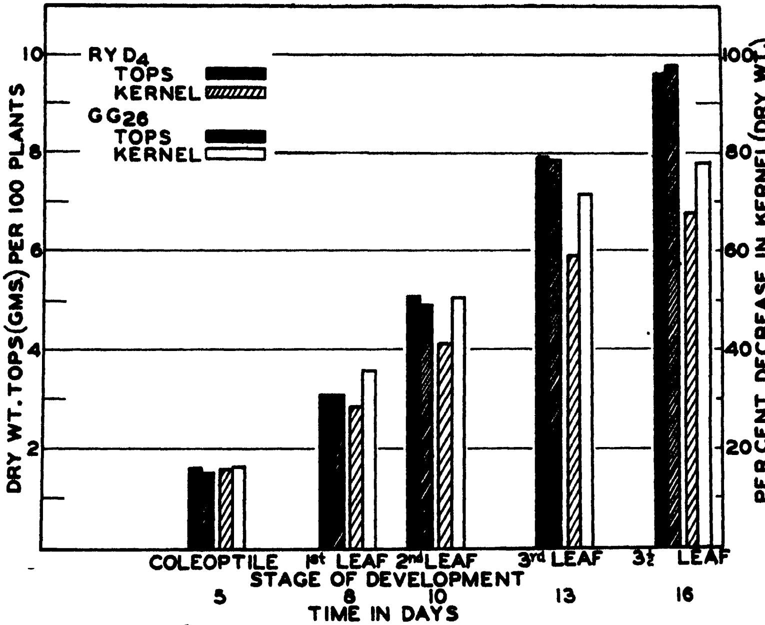

FIG. 1.—Top growth produced and endosperm utilized by seedlings of RYD_4 and GG_{26} grown in the greenhouse at 24°C.

have used practically all their reserves when they have reached the third leaf stage of development (the endosperm represents about 75 to 80% of the total corn kernel), whereas the seedlings of RYD_4 still have a considerable amount of reserve materials left in the kernel.

At a temperature of 17°C (Fig. 2) there is a greater amount of top growth produced by seedlings of RYD_4 than by seedlings of GG_{26}. This difference is small for the first three growth stages and is probably due to the early advantage gained by a more rapid germination of the RYD_4 seed. The increased difference in amount of top growth produced by RYD_4 over that produced by GG_{26} at the third leaf stage is due to a depletion of endosperm reserves in GG_{26} as the seedlings have developed no chlorophyll and are unable to synthesize additional materials for respiration and growth. The rate of top growth for the two inbreds is essentially the same, however, as long as endosperm reserves are available.

The results obtained at 17° also show a greater utilization of endosperm reserves by GG_{26} for the three later stages of development and a greater utilization by seedlings of RYD_4 at the coleoptile stage of

development. Here, as in the case of top growth, the difference at the coleoptile stage of development is due to a more rapid germination in RYD_4 than in GG_{26}. After germination is once started, however, endosperm utilization is considerably faster in GG_{26} than in RYD_4.

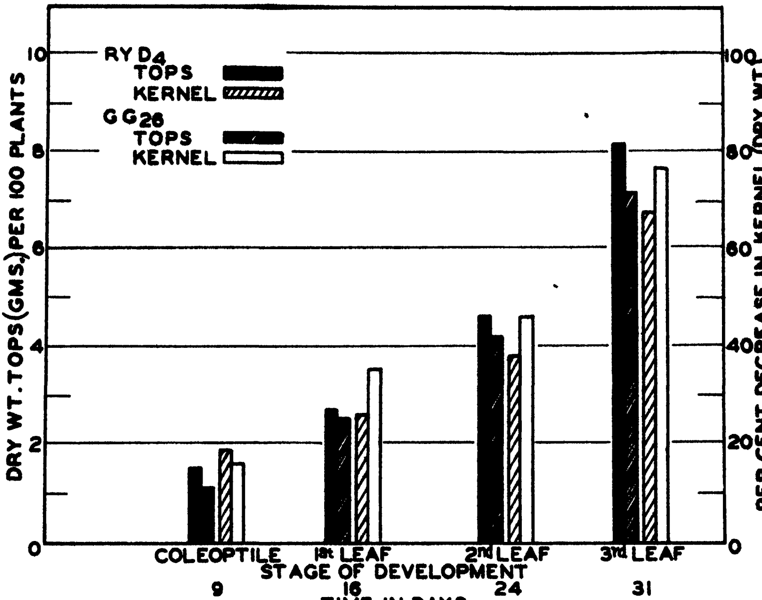

FIG. 2.—Top growth produced and endosperm utilized by seedlings of RYD_4 and GG_{26} grown in the greenhouse at 17°C.

ENDOSPERM UTILIZATION AND TOP GROWTH PRODUCED BY SEEDLINGS GROWN TO THIRD LEAF STAGE AT 24°C THEN SHIFTED TO A LOWER TEMPERATURE

The previous experiments have shown that there is a considerable difference in the amount of endosperm utilized by seedlings of RYD_4 and GG_{26} when grown at either a high or a low temperature. There is, however, practically no difference in the amount of top growth produced at these temperatures during the early seedling stages of development before the endosperm reserves have been depleted. What would be the effect on the growth of these seedlings if they should be subjected to low temperatures about the time the seedlings had reached the third leaf stage of development? The experiments described below represent an effort to answer this question.

Seedlings were grown to the third leaf stage at a temperature of 24° C then shifted to a temperature of 17°C. Data were taken on top growth and endosperm utilization on half the plants in each lot 4 and 8 days after being shifted to the lower temperature. The most advanced stage of development reached by any of these seedlings after being shifted to the lower temperature was the 3½-leaf stage;

therefore, a similar lot of seedlings was grown to the 3½-leaf stage at a temperature of 24°C to serve as a comparison. The results are shown in Fig. 3.

The data show that at the lower temperature there is considerable difference in the amount of top growth produced and endosperm utilized by the two inbreds. The seedlings of RYD_4 continued to grow

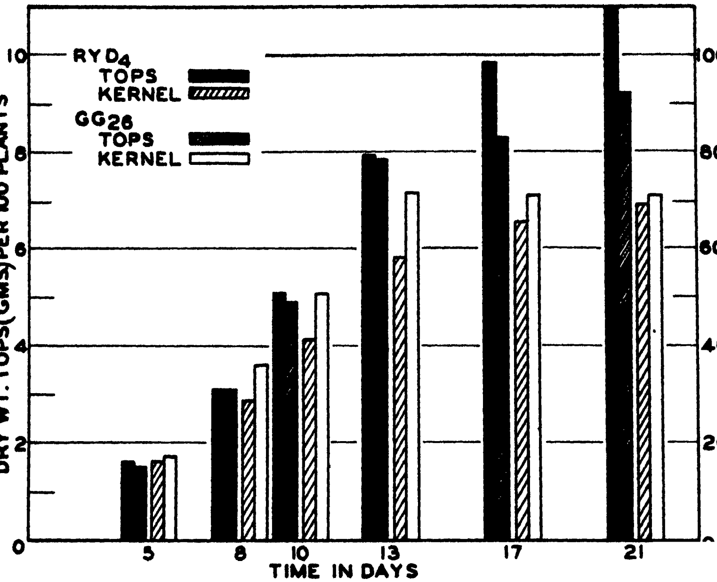

FIG. 3.—Top growth produced and endosperm utilized by seedlings of RYD_4 and GG_{25} grown to third leaf stage (13 days) at 24° C then shifted to 17° C for a period of 4 and 8 days before being harvested.

rather rapidly, whereas the seedlings of GG_{26} produced very little additional top growth after they were shifted to the lower temperature. There was also considerably more endosperm utilized by RYD_4 than by GG_{26}. This, however, was because the endosperm reserves of GG_{26} had been largely utilized by the time the plants had reached the third leaf stage of development and they had no additional reserves from which to draw.

RESISTANCE TO SEEDLING BLIGHT

As pointed out earlier in this paper, there is a marked difference in the ability of these seedlings to develop chlorophyll at a temperature range of 16° to 19°C. Such a contrasting difference indicates a marked difference in the metabolic balance within the young seedlings of these two inbreds. Dickson (3) and Dickson and Holbert (5) have shown that a difference in the metabolic balance within the seedlings of inbred lines of corn is manifest by their resistance or susceptibility to the seedling blight organism *Gibberella saubinetii* (Mont.) Sacc., and that resistance or susceptibility is conditioned principally by the effect of environment on the host rather than on the parasite. It

seemed reasonable, therefore, to test the susceptibility of inbreds RYD_4 and GG_{26} to *G. saubinetii* as an indication of the balance of metabolism within these seedlings. Such a test should indicate to what extent this inability to form chlorophyll at low temperatures is accompanied by a type of metabolism within the plant which influences the degree of resistance or susceptibility to this seedling blight organism.

The experiments on seedling blight were conducted in the greenhouse during the winter. The seedlings were grown in the greenhouse bench in a sandy loam soil at a room temperature of 17°C and a soil temperature of 16°C. Inoculations were made by placing the kernels in a conidial suspension of *G. saubinetii* for 5 to 10 minutes just previous to planting.

The plants were removed from the soil when they had developed to the third leaf stage, washed, and their resistant index calculated on the basis of 0 to 10; 0 representing complete killing and 10 representing freedom from disease.

The results from these inoculations showed a marked difference in the resistance of these two inbreds to the seedling blight organism. The seedlings of GG_{26} were killed completely before the coleoptile and primary roots had elongated to the extent of an inch. The plants of this line which developed further and showed large lesions very probably escaped the disease in the earlier stages of development. In contrast, many of the seedlings of RYD_4 showed small restricted lesions at the point where the seminal roots had broken through the cortical tissue of the cotyledonary node but in most cases had advanced no further. This difference in the resistance to seedling blight is shown in Figs. 4 and 5.

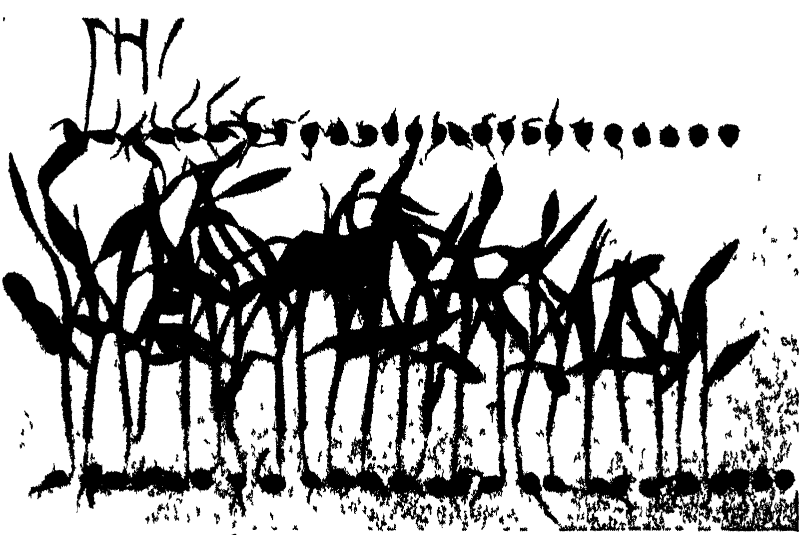

FIG. 4.—Difference in resistance of inbreds RYD_4 and GG_{26} to *G. saubinetii* at a soil temperature of 16°C. Top row GG_{26}, bottom row RYD_4.

Results obtained from inoculating the F_1 progenies showed that they were practically as resistant as the resistant parent. There was a strong indication, however, that the reciprocal crosses between these two inbreds do not behave alike when inoculated with the seedling blight organism. The progenies from the cross GG_{26} X RYD_4

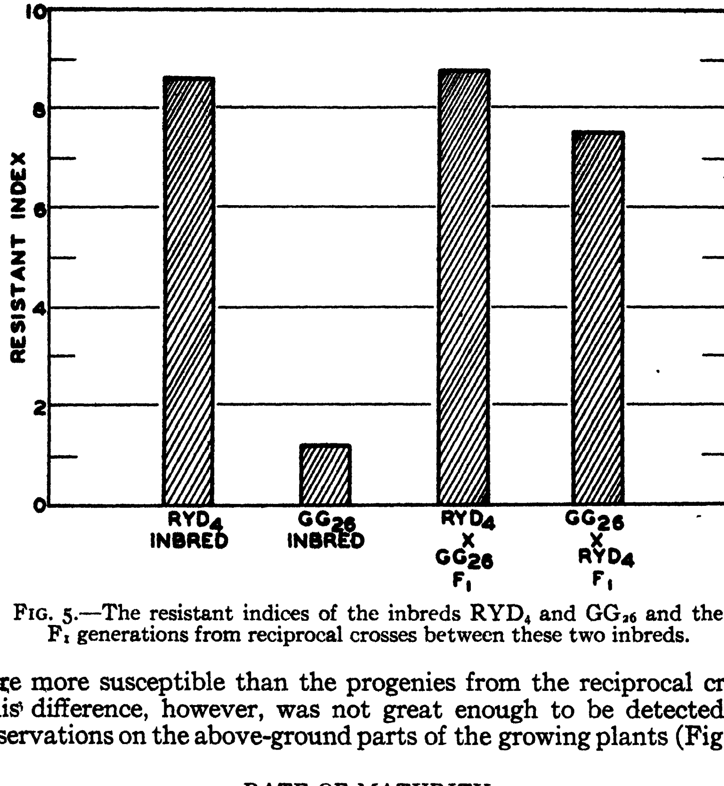

Fig. 5.—The resistant indices of the inbreds RYD_4 and GG_{26} and the F_1 generations from reciprocal crosses between these two inbreds.

were more susceptible than the progenies from the reciprocal cross. This difference, however, was not great enough to be detected by observations on the above-ground parts of the growing plants (Fig. 6).

RATE OF MATURITY

Under field conditions, these inbred lines of RYD_4 and GG_{26} show a considerable difference in the rate of seed maturation. When self-pollinations are made on the same date, plants of RYD_4 mature their seed about 10 days ahead of GG_{26}. This difference in rate of kernel development is evident within a few days following pollination. Such a difference in the rate of kernel maturation may have an important bearing on the factors conditioning the general metabolic balance within these young seedlings.

DISCUSSION

A consideration of the various experiments show that these lines of corn differ in their ability to develop at low temperatures. These two inbreds perhaps show a maximum of contrast in this respect. RYD_4 represents the seedling type which, when grown at low temperatures, is able to synthesize chlorophyll, make an efficient use of

the endosperm reserves, and develop plant tissues which resist the attack of the seedling blight organism. On the other hand, GG_{26} represents a seedling type which is unable to synthesize chlorophyll, makes an inefficient use of its endosperm reserves, and develops plant tissues which are susceptible to the seedling blight organism.

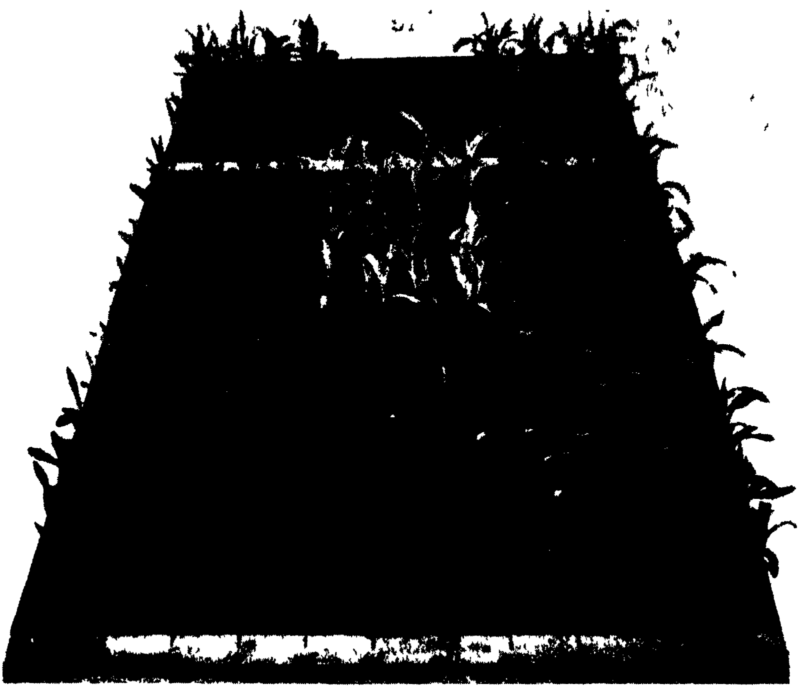

FIG. 6.—The difference in resistance to *G. saubinetii* of inbreds RYD_4 and GG_{26} and the F_1 progenies produced from crosses between these inbreds. Plants were grown at a soil temperature of 16°C. Rows 99–102 RYD_4; rows 103–106 GG_{26}; rows 107–108 RYD_4 x GG_{26}; rows 109–110 GG_{26} x RYD_4. Center panel, check plants, seed not inoculated; near panel, seed inoculated; far panel, seed inoculated.

There is an inter-relationship between endosperm utilization, chlorophyll formation, and tissue development. For example, when no chlorophyll is synthesized, photosynthesis is impossible, endosperm reserves become depleted and the plants die, unless in the mean time conditions have become favorable for chlorophyll formation. On the other hand, when chlorophyll is synthesized the plants are able to maintain a balance between endosperm utilization and photosynthesis which enables them to continue their normal course of growth and tissue development.

The results also show that these seedlings differ in their metabolic balance when grown at a temperature of 16°C. Seedlings of RYD_4 maintain a well-balanced metabolism and produce plant tissues which

will resist the attack of the seedling blight organism, whereas GG_{26} maintains an unbalanced metabolism and develops tissues which are susceptible to the attack of the seedling blight organism.

The unbalanced metabolism which predisposes the plants to the attack of the seedling blight organism is not a direct result of the inability of these seedlings to synthesize chlorophyll at the lower temperatures. The young plants of GG_{26} are attacked and killed by the seedling blight organism before the seedlings have emerged from the soil. Therefore, the lack of ability to synthesize chlorophyll can have little to do with the conditioning of the susceptibility shown by these plants.

The susceptibility to seedling blight may be conditioned earlier than at the seedling stage of development. Hoppe and Holbert (9) have shown that inbreds which have an extended type of maturation in the fall are more susceptible to seedling blight than those which mature earlier. This is in good agreement with field observations on inbreds RYD_4 and GG_{26}. Plants of RYD_4 mature kernels more rapidly in the fall than GG_{26} and are also more resistant to *Gibberella* seedling blight in the seedling stage of development.

The more rapid kernel development by RYD_4, is evident long before the corn is mature in the fall. Within 4 or 5 days following pollination, endosperm development is apparent in RYD_4, whereas in GG_{26} about a week elapses after pollination before it is possible to determine whether or not pollination has been effective. From this standpoint, however, it is assumed that approximately the same length of time elapses between pollination and fertilization in these two inbreds. If a difference in the rate and type of maturation of the kernel influences the degree of resistance which will be manifest by the seedling plant, this would explain, in part at least, the difference in in the degree of resistance to seedling blight shown by the F_1 seedlings from reciprocal crosses between these two inbreds.

The results also show that resistance to seedling blight is dominant in this cross. The F_1 plants showed practically the same degree of resistance as the resistant parent. There is a possibility, however, that heterosis enables the F_1 plants to outgrow the parasite. This is unlikely, however, as there were restricted lesions on the F_1 plants at the point of emergence of the seminal roots. This would indicate that they were resisting the parasite rather than outgrowing it.

SUMMARY

This paper deals with a study of the comparative ability of seedlings of two inbred lines of corn to grow at low temperatures and maintain a well-balanced type of metabolism during the early stages of seedling development.

The studies were limited to two contrasting inbreds known as RYD_4 and GG_{26} and subsequent progenies produced from crosses between these two inbreds. When grown in the greenhouse during the winter at a temperature range of 16° to 19°C, the seedlings of RYD_4 were a normal green color, whereas the seedlings of GG_{26} were typically virescent, being almost devoid of chlorophyll. Both inbreds were green when grown at a temperature of 24°C.

This virescent character is probably inherited as a simple recessive to normal green.

Extraction of the chlorophyll and carotinoid pigments showed that in the seedlings of GG_{26} carotin was formed only when chlorophyll formation occurred. Xanthophyll, however, was formed in the absence of the chlorophyll pigments.

Endosperm utilization was more rapid in seedlings of GG_{26} than in seedlings of RYD_4 when grown at a temperature fo 17° or 24°C. The endosperm reserves of GG_{26} were practically exhausted when the seedlings had developed to the third leaf stage, whereas seedlings of RYD_4 had considerable reserve materials left at this stage of development.

The amount of top growth produced by the seedlings of these two inbreds was essentially the same when grown at 17° and 24°C. There was a greater amount of top growth produced by inbred RYD_4, however, when the plants were grown to the third leaf stage at a temperature of 24°C then shifted to a temperature of 17°C for a period of 4 and 8 days.

At a soil temperature of 16°C the seedlings of RYD_4 were highly resistant to *Gibberella* seedling blight, whereas seedlings of GG_{26} were very susceptible. The F_1 progenies showed about the same degree of resistance as the resistant parent. Seedlings of the cross RYD_4 X GG_{26} were more resistant than the F_1 progenies of the reciprocal cross.

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ANALYSIS OF VARIANCE OF CORN YIELDS OBTAINED IN CROP ROTATION EXPERIMENTS[1]

R. J. GARBER AND T. C. MCILVAINE[2]

IN 1925 a crop rotation experiment involving 270 plats was established at the Lakin Experiment Farm near Point Pleasant, W. Va. The general plan of procedure and a diagram of the location of the plats have been published (2),[3] hence need not be repeated here. The purpose of this paper is to present the results of an analysis of variance of the corn yields obtained during 9 years, 1925 to 1933, inclusive, in three 4-year, three 3-year, and three 2-year rotations. Each rotation contained corn grown for grain as one of the crops. Each crop in the rotations was grown each year on duplicated plats of approximately 1/51 acre net in both the limed and unlimed series. On the former series finely ground limestone was applied as needed to maintain the pH level at approximately 7. All plats received annually about 200 pounds of superphosphate. The soil was mapped as Wheeling fine sandy loam by the Bureau of Chemistry and Soils of the U. S. Dept. of Agriculture (5).

Unfortunately, the plats in this experiment were not distributed in randomized blocks, but it was thought that the systematic distribution used did give at least a fairly adequate systematic sampling of the variability in the field. In this connection the juxtaposition of the plats compared should be taken into consideration. The location of the plats may be ascertained from Table 1 and from a diagram in the previous publication (2, p. 256).

TABLE 1.—*The number labels of the plats involved in the unlimed series in certain rotation experiments at the Lakin Experiment Farm, Lakin, W. Va.*

Plat numbers	Block
4-year rotations:	
1–3, 13–15, 25–27, 33–35	I
111–113, 123–125, 135–137, 143–145	II
3-year rotations:	
6–8, 18–20, 30–32	I
116–118, 128–130, 140–142	II
2-year rotations:	
9–11, 21–23	I
119–121, 131–133	II

The number labels shown in Table 1 are for the unlimed series. The corresponding limed plats carry numbers that are greater by 50. For example, plats 1 and 51 which occur end to end in block 1 are occupied by the same crop of a given rotation, but plat 51 receives lime and plat 1 does not. A similar differential treatment distinguishes plats 2 and

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[3]Reference by number is to "Literature Cited," p. 485.

52, 3 and 53, 13 and 63, etc. Consecutively numbered plats in the field are in contiguous (side by side) positions. All the plats and treatments in block I are duplicated in block II. A total of 108 different plats were involved of which 36 were in corn each year.

Another criterion may be used as a measure of the adequacy of systematic sampling in this instance. It has been shown (3) that the yields obtained during the first 5 years of the rotation experiment were positively correlated with the yields of a uniformity crop of oats harvested previously. The question arises as to whether the systematic location of plats in blocks I and II truly represented the variance that existed in these blocks. Using Table 1 to locate the plats and the yields (2) of the uniformity crop of oats, an analysis of the variance in each block may be made by means of the methods developed by Fisher (1). The results of such an analysis are shown in Table 2.

TABLE 2.—*Analysis of variance of yields of a uniformity crop of oats grown in 1923 on certain plats at the Lakin Experiment Farm, Lakin, W. Va.*

Block	Variation	Degree of freedom	Sum of squares	Mean squares	½ log$_e$ of mean square	Z*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
I	Between groups...	2	185,134	92,567	5.7179	
	Within groups....	51	3,561,517	69,834	5.5769	0.1410
	Total............	53	3,746,651	70,692	5.5831	
II	Between groups...	2	16,656	8,328	4.5137	
	Within groups....	51	2,680,316	52,555	5.4348	0.9211
	Total............	53	2,696,972	50,886	5.4187	

*A Z value of 0.5738 is necessary where n_1 = 2 and n_2 = 60 for a 5% level of significance, and where n_1 = 51 and n_2 = 2 a Z value slightly in excess of 1.4840 is necessary for a similar level of significance according to Fisher's (1) 5% table.

The yields of the uniformity oats obtained from the 12 plats in block I now occupied by the 2-year rotations were placed in one group; similarly, those from the 18 plats now in the 3-year rotations in a second group; and those from the 24 plats now in the 4-year rotations in a remaining group. The same procedure was followed with the uniformity yields obtained in block II.

It is apparent from Table 2, particularly from the Z values recorded in column 7, that the variance between groups and within groups is not significantly different, either among the plats in block I or among those in block II. Likewise, it may readily be determined that neither the variance between groups nor that within groups differs significantly from the total variance in a particular block. This is interpreted to mean that insofar as the uniformity crop is concerned the systematic arrangement of the plats in a certain block with respect to 2-, 3-, and 4-year rotations gave a representative sample of the total variance in that block.

CORN YIELDS

The yields of corn in the rotation experiments were determined and were expressed on the basis of air-dry shelled corn. The individual

plat yields are not recorded here but are available on mineographed sheets to anyone interested. The average yield of corn in block I for the 9-year period was approximately 3.1 bushels more than in block II.

ANALYSIS OF VARIANCE

In Table 3 are recorded the results of analyzing the variance in the 324 corn yields. In column 1 the sources of variation are shown and in column 2 the degrees of freedom. There is one degree of freedom for blocks since the experiment was carried on in duplicate. Nine different rotations are involved on both limed and unlimed plats and therefore there are eight degrees of freedom for rotations and one for lime treatment. Similarly, since the work was carried on for 9 years, there are eight degrees of freedom for years. The degrees of freedom for the several interactions may be determined by simple multiplication.

TABLE 3.—*Analysis of variance of yields of corn obtained in certain rotation experiments during 9 years at the Lakin Experiment Farm, Lakin, W. Va.*

Variation due to	Degree of freedom	Sum of squares	Mean squares	½ $\log_e$ of mean square	Z
(1)	(2)	(3)	(4)	(5)	(6)
Blocks	1	820.82	820.820	3.3552	1.4416*
Rotations	8	21,830.00	2,728.750	3.9558	2.0422*
Lime	1	1,801.06	1,801.060	3.7481	1.8345*
Years	8	24,281.41	3,035.176	4.0090	2.0954*
Blocks x years	8	521.32	65.165	2.0885	0.1749
Rotations x years	64	14,924.91	233.202	2.7260	0.8124*
Rotations x lime	8	571.11	71.389	2.1341	0.2205
Lime x years	8	603.03	75.379	2.1612	0.2476
Years x rotations x lime	64	2,150.99	33.609	1.7574	—0.1562
Blocks x rotations	8	total for error			
Blocks x lime	1				
Blocks x years x rotations	64				
Blocks x years x lime	8				
Blocks x rotations x lime	8				
Blocks x years x rotations x lime	64				
Error	153	7,027.75	45.933	1.9136	
Grand total	323	74,532.40			

*Significant according to Fisher's 1% table.

The interactions making up the estimate of error are delineated separately, but it is not necessary to calculate separately their contribution to sum of squares (column 3) because their combined contribution is all that is of interest. In this experiment the two differentials introduced in the plan were rotations and lime treatment, and therefore it would seem that the various interactions between them, on the one hand, and the blocks, on the other, would constitute a legitimate estimate of error. The variance attributable to blocks and to interaction between blocks and years may be eliminated since the experimental differentials are balanced (or would be so theoretically if the arrangement had been randomized throughout) in these two

sources of variation. A total of 153 degrees of freedom is available on which to base the estimate of error.

In column 6, Table 3, are recorded the Z values which are the differences between ½ $\log_e$ of mean square (1.9136, column 5) of the error and that of each of the other sources of variation. The Z values that are starred are significant as determined from Fisher's (1) 1% table. It may be observed that the variation due to blocks, rotations, lime treatment, years, and the interaction between rotations and years are significant. The fact that the variation due to blocks is significant shows that a worthwhile reduction in the estimate of error has been made by design of the experiment. The rotations, as well as the lime treatment, apparently are responsible for significant variations in the corn yields. The seasonal effect of the different years on the yield of corn is likewise significant. The fact that the interaction between rotations and years is of importance shows that the relative influence of the rotations on corn yields is not the same in the different seasons. One might wish to analyze this differential response further. This could be done in a manner similar to that suggested recently by Immer, Hayes, and Powers (4).

The other sources of variation are not significant as determined from the Z values and Fisher's 1% table. The lime treatments gave about the same relative response in the different rotations as measured by the corn yields. Similarly, the limed and unlimed plats maintained their relative corn yields throughout the duration of this experiment. In view of the last two statements, it is not surprising to find no significant double interaction among years x rotations x lime.

If it were desired to examine the significance of a difference between the average or the total yields of some particular plats, the standard error might be used. For this purpose the standard error of a single plat yield may be obtained by extracting the square root of the mean square (last mean entered in column 4) for error. This is found to be 6.777.

It will be recalled that the rotations involved in this analysis include three 4-year, three 3-year, and three 2-year rotations. Since a considerable part of the variation in the corn yields was contributed by them, it may be of interest to separate this variation into its two components, namely, that between groups of rotations based upon length of rotation and that between rotations of the same group. This has been done in Table 4.

TABLE 4.—*Analysis of variance of corn yields attributable to crop rotations.*

Variation	Degree of freedom	Sum of squares	Mean squares	½ $\log_e$ mean square	Z
(1)	(2)	(3)	(4)	(5)	(6)
Between rotations in general..	8	21,830.00	2,728.750	3.9558	—
Between rotation groups (2-, 3-, and 4-year rotations)...	2	20,612.51	10,306.255	4.6203	—
Between rotations within groups..................	6	1,217.49	202.915	2.6564	1.9639

Table 4 shows that the variation from group to group among the 2-, 3-, and 4-year rotations is greater than the variation among the rotations within the same group as measured by the corn yields. The Z value (column 6) obtained by taking the difference of ½ $\log_e$ of mean squares between these two sources of variation is 1.9639, a significant number. Moreover, the variation contributed by groups as well as that contributed by rotations within groups is significant when compared with that due to error (Table 3). For this comparison, the Z value for rotation groups was 2.7067 and that for rotations within the same group 0 7428.

CORRELATION BETWEEN THE YIELDS OF A UNIFORMITY CROP AND CORN

Before the rotation experiments were begun in 1925 the entire area involved had been previously cropped to oats in 1923 and to wheat in 1924. The correlations between the yields of these uniformity crops and the yields obtained during the first 5 years of the rotation experiments have been reported In Table 5 the correlations are shown between the yields of corn in the rotations under discussion in the present paper and the yields of the uniformity oat crop on the same plats

TABLE 5.—*Correlations between the yields per plat of a uniformity oat crop grown in 1923 and the yields on the same plats of corn in the rotation experiments during subsequent years at the Lakin Experiment Farm, Lakin, W. Va.*

Year of corn crop	n	r*
(1)	(2)	(3)
1925	36	0 370
1926	36	0.525
1927	36	0 559
1928	36	0.161
1929	36	0.482
1930	36	0.280
1931	36	0 036
1932	36	0.521
1933	36	0.016
1925–29	180	0.391
1930–33	144	0.290
1925–33 . . .	324	0.346

*According to Fisher s (1) V A table, an r value of at least 0 330 is necessary where n = 36 for odds of 19 to 1 (P = 05) for significance

All the correlations in column 3 of Table 5 are positive although four of the nine interannual correlations are not statistically significant. This perhaps is not surprising in view of the fact that n in these studies was only 36. In 1930, the year of the drought, the rainfall at Lakin was much below the average during the growing season. For this reason the yields of corn from 1925 to 1929 and from 1930 to 1933, inclusive, were correlated separately with the yields of the uniformity crop. The correlation for the first period is 0.391 and for the second is 0.290, both being significant The correlation coefficient between all the corn yields and the corresponding yields of the uniformity crop is 0.346.

The correlations presented in Table 5 show very definitely that an appreciable amount of the total variation in the corn yields may be accounted for by the different levels of natural productivity that existed among the plats when the rotation experiments were begun, as measured by a uniformity crop. In view of this fact the experimental error might be reduced still further by analyzing the covariance between the yields of the uniformity crop and the corn yields obtained subsequently.

SUMMARY

A brief discussion is presented of the effectiveness of the "analysis of variance" method as developed by Fisher (1) in analyzing certain corn yields obtained over a period of 9 years in a rotation experiment at Lakin, W. Va. An example is given of a systematic arrangement of plats that proved to be truly representative.

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DEFOLIATION EXPERIMENTS WITH KAOLIANG (*ANDROPOGAN SORGHUM*)[1]

H. W. Li and T. N. Liu[2]

KAOLIANG is one of the most important food crops in North China. Farmers of that region have a practice of removing all the leaves except the top few at the time when the kernels are about in the dough stage. On account of lack of fuel and the deficiency of forage, the leaves thus obtained are used to advantage. Besides, the farmers claim that by means of defoliation maturity can be hastened to some extent. It is obvious that the leaves are vital for the plant to manufacture its food. When the plant is made destitute of its food factories, its yield of grain, which is the ultimate aim for growing the crop, naturally must be affected. The present experiments were planned to determine the amount of reduction in yield due to defoliation, and the time at which defoliation can be done with the least effect on the yield of the plant.

MATERIAL AND METHODS

The land on which this experiment was carried out was very level and was sandy loam in composition for the top 3 feet. This field had been sown to uniform crops for several previous cropping seasons. The rows were 45 feet long and 2 feet apart. An inbred stock of seed was used to insure uniformity. Hill planting was resorted to, with eight seeds planted in each hill. The distance between the hills was 1½ feet.

Planting was done on April 14. When the seedlings were about 3 inches high, each hill was thinned to one plant. Any missing hills were promptly taken care of by transplanting. Thus, an almost perfect stand was obtained. There were altogether 270 rows in the experiment and these were divided into nine different treatments with 10 replications for each. (Each treatment had three rows to form one plat.) The plats were laid out in a systematic manner. For every other two treatment plats there was an untreated check plat. Thus, in the whole experiment, there were six different treatment plats and three check plats. Defoliation was done by holding the leaf blade and pulling it off with a snap, leaving only the part that consists of the leaf sheath on the stalk. The plats of this experiment were harvested on August 11. Apparently there was no clear difference in the degree of maturity.

ANALYSIS OF EXPERIMENTAL DATA

Table 1 gives the yield of the individual plats (average of three rows) in the 10 replications for the different kinds of treatments.

From Table 1 it will be seen that the yields of the check plats are very uniform. In order to show the significance of the results obtained (Table 2), Fisher's method for the analysis of variance is used (1).[3]

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[1]Contribution from the College of Agriculture, Honan University, Kaifeng, Honan, China. Received for publication March 23, 1935.

[2]Professor and Associate in Plant Breeding, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 491.

TABLE 1.—*Yield of the 90 plats of kaoliang in grams.*

Treatment*	Blocks†										
	1	2	3	4	5	6	7	8	9	10	Total
A.......	739	895	928	936	769	840	1,075	1,089	970	885	9,126
B.......	1,040	980	1,081	1,020	1,020	1,015	1,163	1,230	1,159	1,010	10,718
Ck_1.....	1,195	1,220	1,118	1,061	1,189	1,318	1,369	1,325	1,202	1,121	12,118
C.......	1,093	1,039	1,142	1,195	1,323	1,330	1,205	1,319	1,266	1,189	12,101
D.......	298	381	390	307	256	373	307	386	322	339	3,359
Ck_2.....	1,200	1,085	1,108	1,235	1,217	1,259	1,319	1,179	1,216	1,140	11,958
E.......	924	874	932	776	872	923	1,045	932	982	629	8,889
F.......	1,256	1,199	949	1,286	1,120	1,189	1,288	1,150	1,148	1,004	11,589
Ck_3.....	1,160	1,131	1,158	1,243	910	1,428	1,291	1,339	1,320	1,170	12,150
Total....	8,905	8,804	8,806	9,059	8,676	9,675	10,062	9,949	9,585	8,487	92,008

*A = Starting July 5, two leaves were removed every other 5 days (starting from the bottom) until all the leaves were removed.
B = On August 1, all leaves removed. Kernels were about in dough stage.
C = Same as B, but three leaves on top left, as commonly done by farmers.
D = When plants bloomed (¾ of the head), all leaves removed.
E = When the kernels of each plant reached the milk stage, all leaves removed.
F = The leaves removed as the kernels of each plant reached the dough stage.
Ck = Untreated plats.
†Three rows each.

TABLE 2.—*Analysis of variance of data in Table 1.*

Variation due to	d. f.	Sum of squares	Mean square	F
Treatments................	8	6,605,092.72	825,636.50	114.29
Blocks	9	320,079.08	35,564.34	———
Error.	72	520,149.72	7,224.30	———
Total.....................	89	7,445,321.52	———	———

From Table 2 the F (2) obtained is very large (for $n_1 = 8$, $n_2 = 70$, F at the 5% point is 2.07 and at the 1% point is 2.78). This means that the treatments are significantly different from one another. The standard error of the mean of the 10 plats is $\sqrt{\frac{7224.30}{10}}$. Any significant difference then should be $\sqrt{\frac{7224.30}{10}} \times \sqrt{2} \times 1.96 = 74.9$. A difference greater than 74.9 is considered significant. The comparison of the different treatments is shown in Table 3.

TABLE 3.—*Comparison of yield for different treatments.**

	B	C	D	E	F	Ck
A......	−159.2	−297.5	+581.7	+28.7	−241.3	−289.9
B......	———	−138.3	+735.9	+182.9	− 87.1	−135.7
C......	———	———	+874.2	+321.2	+ 51.2	+ 21.6
D......	———	———	———	−553.0	−823.0	−871.6
E......	———	———	———	———	−270.0	−318.6
F......	———	———	———	———	———	− 48.6

*Level of significance between two treatments = $\sqrt{\frac{7,224.30}{10}} \times \sqrt{2} \times 1.96 = 74.90$.

Taking the comparison of the different treatments with the average of the check plats first, it can be seen that, except for treatment C which has an insignificant increase of yield over the check, all others show a reduction in yield. All the reductions are statistically significant except that of treatment F. In treatment A, two leaves were taken off at 5-day intervals. This causes a gradual reduction of the leaf area. The significant reduction in yield as compared with the check should discourage farmers from starting defoliation too early even if there is an urgent need for the leaves. By removing all the leaves when the plants reach the dough stage, as in treatment B, a significant reduction in yield is again obtained. However, when all the leaves are removed except three at the top, as in treatment C, we find an insignificant increase over the check plat.

In order to show the critical stage at which the plants will either suffer or will not be affected by defoliation, individual plants were treated separately in the row. In treatment D defoliation was done when two-thirds of the heads reached the blooming stage, the plants being stripped of all the leaves. This is the most severe of all the treatments and resulted in the greatest reduction in yield. Defoliation at the time the plant reached the milk stage, as in treatment E, also resulted in a significant reduction in yield, but less than that in treatment D. By the time the plant has reached the dough stage, the leaves have performed their duty and defoliation will not affect the yield of the plant at all. Thus, treatment F showed a reduction in the yield as compared with the check, but it was statistically insignificant.

Since defoliation at the critical period results in the reduction of yield of kaoliang, it was desired to determine the cause of this reduction. Is it due to the reduction in the weight of the individual kernels or to the number of kernels per plant, or both? It is difficult to determine the exact number of kernels of an individual plant, but it is comparatively easy to find out the weight of the individual kernels. Table 4 gives the weight of 100 kernels in grams for the 90

TABLE 4.—*Weight of 100 kernels in grams for each plat of the different treatments.*

Treatments*	Blocks†										
	1	2	3	4	5	6	7	8	9	10	Total
A	1.35	1.66	1.67	1.65	1.54	1.65	1.88	1.88	1.61	1.55	16.44
B	1.69	1.96	1.89	1.91	1.87	1.91	1.90	1.96	1.90	1.90	18.89
Ck_1	1.96	2.14	2.01	1.99	2.00	2.13	2.06	2.02	2.12	1.96	20.39
C	1.89	2.06	2.02	2.01	1.99	2.14	1.97	1.97	2.04	1.98	20.07
D	1.08	1.21	1.09	1.03	1.08	1.19	1.07	1.24	1.16	1.09	11.24
Ck_2	2.01	2.07	2.10	2.02	2.03	2.04	2.01	2.11	2.08	1.96	20.43
E	1.67	1.53	1.58	1.58	1.50	1.53	1.70	1.69	1.69	1.54	16.01
F	2.00	1.81	1.96	1.90	2.13	2.05	2.07	1.96	2.05	1.89	19.82
CK_3	2.03	2.03	2.00	1.99	2.06	2.13	2.07	2.10	2.10	1.95	20.46
Total	15.68	16.47	16.32	16.08	16.20	16.77	16.73	16.93	16.75	15.82	163.75

*See Table 1 for plan of treatments.
†Three rows each.

plats with the samples taken at random, and Table 5 gives the analysis of variance of the data.

TABLE 5.—*Analysis of variance of data in Table 4.*

Variation due to	d. f.	Sum of squares	Mean square	F
Treatment	8	7.7881	0.9735	177
Blocks	9	0.1907	0.0212	—
Error	72	0.3945	0.0055	—
Total	89	8.3733		—

F in this case is also very large for the same n_1 and n_2 as in Table 2. Thus it shows clearly the significant difference between the treatments. The comparative difference between the treatments is shown in Table 6.

TABLE 6.—*Comparison of the weight of 100 kernels for different treatments.**

	B	C	D	E	F	Ck
A	—0.25	—0.37	0.52	0.04	—0.34	—0.40
B	—	—0.12	0.77	0.29	—0.09	—0.15
C	—	—	0.89	0.41	0.03	—0.03
D	—	—	—	—0.48	—0.86	—0.92
E	—	—	—	—	—0.38	—0.44
F	—	—	—	—	—	—0.06

*Level of significance between two different treatments $= \sqrt{\frac{0.0055}{10}} \times \sqrt{2} \times 1.96 = 0.651$

In general, the difference in the kernel weight for the different treatments agreed closely with that for the yield, except for treatment C. In this case it has an insignificant decrease of an increase.

In order to show the correlation of the two variables yield and weight of 100 kernels, an analysis of covariance was calculated and is shown in Table 7.

TABLE 7.—*Analysis of variance and covariance.*

Variation due to	d. f.	Sum of squares $(x)^2$ A	Sum of products (xy) B	Sum of squares $(y)^2$ C	$\frac{B^2}{A}$
Blocks	9	0.1907	196.870	320,079.08	—
Treatments	8	7.7881	7,106.612	6,605,092.72	—
Error	72	0.3945	110.528	520,149.72	30,966.89
Total	89	8.3733	7,414.010	7,445,321.52	—

The regression coefficient is $\frac{110.528}{0.3945}$. To test its significance we have $B^2/A = 30{,}966.89$. Hence an analysis of yield error is given in Table 8.

After an allowance is made for treatment and blocks, high yield is associated with heavier kernel weight, and *vice versa*. The value of r is .244 when n = 70; r at 5% level is .2319. The correlation coeffi-

TABLE 8.—*Analysis of yield error.*

	d. f.	Sum of squares	Mean square	F
Due to regression	1	30,966.89	30,966.890	4.49
Due to deviation	71	489,182.83	6,889.899	—
Total error	72	520,149.83	—	—

$N_1 = 1$ $F = 5\%$ 1%
$N_2 = 70$ 3.98 7.01

cient thus obtained is significant. We may conclude, therefore, that yield depends partly at least on the weight of individual kernels.

DISCUSSION

Some defoliation experiments have been conducted with *Zea Mays* by several American agronomists (3, 4), and the results obtained in the present experiment seem to agree closely with those for *Zea*, i. e., a reduction in yield and weight of kernels resulting from defoliation, according to the time defoliation is done. When the plant reaches the dough stage, the function of the leaves comes to an end. In fact, by this time, the leaves are turning yellow and are gradually drying up. Practically, most of the surplus food materials manufactured by the leaves have already been translocated to be stored up in the seeds. Stripping the leaves off at this stage would mean no loss to the plant at all so far as surplus food material is concerned. However, prior to this stage, reduction in the leaf surface would mean reduction in the weight of the grains produced and thus a reduction in yield. As it is the custom of farmers to defoliate only when the plants reach the dough stage or later, no reduction of yield is to be expected.

It seems that maturity is not hastened by defoliation, as can be observed superficially at least in this experiment. Nevertheless, when the leaves are removed from the lower part of plants in the field, free circulation of air can thus be obtained. This may mean a more rapid rate of transpiration and evaporation. Thus, the kernels of the plant might in this way give off water at a faster rate. However, a careful test must be carried out before any definite conclusion can be drawn.

SUMMARY

Kaoliang defoliation at the time when the plant reaches the dough stage results in insignificant reductions both in yield and in kernel weight.

Any defoliation done prior to this stage results in reduction both in yield and in kernel weight, the reduction being directly proportional to the earliness of defoliation.

The method used in stripping off the leaves from the kaoliang plant by farmers, i. e., at the dough stage and leaving a few leaves at the top of the plant, does not affect the yield and the kernel weight at all.

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INHERITANCE OF ANNUAL HABIT AND MODE OF POLLINATION IN AN ANNUAL WHITE SWEET CLOVER[1]

ALFRED E. CLARKE[2]

THROUGH the courtesy of Dr. L. W. Kephart, several species of *Melilotus* were obtained from the Bureau of Plant Industry, U. S. Dept. of Agriculture. One lot of seed was listed under the name *M. altissima* (Forage Plant Introduction No. 74479). When grown in the greenhouse it proved to be an annual white-flowered sweet clover. The plants appeared similar in morphological characters to those of Hubam sweet clover, an annual variety of *M. alba* generally thought to have arisen from the biennial type through mutation. According to Pieters and Kephart (13)[3], the importance of the annual variety was first recognized by Hughes, although it was probably observed by Tracy as early as 1898. In 1918, *M. alba* Desr. var. *annua* Coe was named and described by Coe (4). Smith (14) found that in crosses between Hubam and the biennial type the annual habit is inherited as a simple dominant.

INHERITANCE OF ANNUAL HABIT

The annual white-flowered strain obtained from the Bureau of Plant Industry was crossed with common biennial white sweet clover and two seeds were obtained. One produced an annual plant, like the female parent, and undoubtedly arose from accidental self-pollination. The other plant showed marked hybrid vigor since it was the largest sweet clover plant in the greenhouse, although grown to maturity in a small flower pot. In time of flowering it behaved as an annual but was later than the other annuals planted on the same date, probably on account of its greater vegetative growth. In the F_2, 202 annual and 60 biennial plants were obtained. This is a satisfactory fit to a 3:1 ratio, as shown in Table 1, and corresponds with the results obtained by Smith (14) in his study of the inheritance of the annual habit in Hubam sweet clover.

TABLE 1.—*Observed and expected frequencies in an F_2 population segregating for annual and biennial habit of growth.*

Cross	Observed		Expected (on 3:1 basis)		Dev. in numbers	P. E.	Dev. / P. E.
	Annual	Biennial	Annual	Biennial			
Annual x biennial	202	60	196.5	65.5	5.5	±4.73	1.2

[1]This paper represents a part of the work carried out by the author at the University of California while holding a National Research Council Fellowship in the Biological Sciences. Received for publication April 6, 1935.

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[3]Numbers in parenthesis refer to "Literature Cited", p. 496.

Reciprocal crosses were made between this annual white strain and the Hubam variety to determine if both carried the same dominant factor for the annual habit. This proved to be so, since all of the F_1 plants were annual, and the F_2 progenies also bred true for the annual habit. Since the two strains were of different origin, it would seem that the mutation must have arisen independently in the two cases.

In a progeny of biennial spreading dwarf plants, a strain described in an earlier paper (2), a single plant was obtained which proved abnormal in its time of flowering. A few of its branches, arising from one portion of the crown, flowered much earlier than the others and were apparently annual. The remainder of the plant behaved as a biennial. The late-flowering part of this plant began blooming earlier than any of the other plants in the same progeny. A careful examination of its roots showed that only one plant was involved.

The plant was caged and the flowers tripped individually to insure self-pollination. Although the pollen grains appeared normal when viewed under the microscope, few seeds were obtained from the early-flowering portion of the plant and none from the late-flowering branches. No cytological irregularities were observed in root tip preparations from this plant. This result is not surprising since cytological studies reported in an earlier paper (3) failed to show any differences in chromosome morphology between the chromosome set of biennial *M. alba* and that of *M. alba annua*.

Seeds from the annual part of the plant produced five annual and three biennial plants. The number of plants in the population is too small to establish the mode of inheritance, but this probably represents a 3:1 ratio, with the annual character behaving as a dominant.

It seems probable that there occurred in this plant a dominant somatic mutation, making the annual portion heterozygous for time of flowering. It should be borne in mind that no dormant period is required in biennial sweet clover before flowering and that biennial plants frequently produce a few flowers during the first year's growth. In this genus, therefore, a change from the biennial to the annual habit is only a change in time of maturity. Nevertheless, these results do suggest the manner in which annual species or subspecies may sometimes be derived from biennial species.

INHERITANCE OF MODE OF POLLINATION

A knowledge of the mode of pollination of a species and whether or not it is self-sterile is important in genetical studies and also in practical plant breeding. Sweet clover species and strains differ markedly in the readiness with which they set seed after self-pollination, and there is considerable difference of opinion over the reason for such differences.

Müller (12) noted that in common yellow sweet clover, *M. officinalis*, the pistil is longer than the stamens, so that self-pollination is rendered unlikely. Darwin (5) reported that a plant of this species, when protected from insect visits produces few seeds while an unprotected plant produces many. Knuth (11) listed *M. officinalis* as

self-sterile. Kirchner (7) found that in common white sweet clover, *M. alba*, self-pollination occurs regularly. Both Kirk (8) and Elders (6) conclude that white sweet clover is highly self-fertile, while yellow sweet clover is either somewhat self-sterile or very sensitive to caging. Kirk and Stevenson (9, 10) have pointed out that in *M. alba* close proximity of stigmas and anthers seems to facilitate self-pollination, but this does not always hold in *M. officinalis*. The chief factor in natural self-pollination in *M. alba* seems to be the distribution of the pollen within the unopened flowers which in turn depends on the relative length of the stamens and style, the amount of pollen produced, and the size of the cavity in the upper part of the keel.

Recently, Brink (1) has shown that self-incompatibility in *M. officinalis* is caused by a reduced rate of germination of a plant's own pollen on its stigma and the slow growth of the pollen tubes under these conditions.

Ufer (15, 16) has listed some species which do not naturally self-pollinate and others in which good seed setting always accompanies natural self-pollination. With *M. altissimus*, *M. sulcatus*, *M. italicus*, and *M. albus annuus* the results vary between plants within the particular species. The results are much more uniform within single plant progenies than between unrelated plants.

The writer noted that some plants of the annual white strain, Forage Plant Introduction No. 74479, have pistils of the same length as the stamens, while in other plants the pistils are longer than the stamens. This suggests that differences in style length between individual plants may account, at least in part, for differences in seed-setting capacity between plants of this strain when grown in the greenhouse under cages to exclude insects and insure self-pollination. Some racemes were tripped, while others were left untripped as controls. The results obtained are shown in Table 2.

TABLE 2.—*Effect of artificially tripping blossoms in a strain of annual white sweet clover (F. P. I. No. 74479).*

	Pistil and stamens of the same length		Pistil longer than stamens	
	Untripped	Tripped	Untripped	Tripped
No. of plants	7	7	4	4
No. of flowers	3,267	3,334	2,274	1,566
No. of pods	1,335	2,023	321	656
Per cent pods	40.9±7.0	60.7±6.2	14.1±4.2	41.3±9.4
Odds that difference is significant, calculated from original data by Student's method	75.9 to 1		322 to 1	

Difference in percentage of pods obtained from untripped flowers with pistil and stamens of the same length, and from untripped flowers with pistil longer than the stamens	26.8± 8.2
Difference in percentage of pods obtained from tripped flowers with pistil and stamens of same length, and tripped flowers with pistil longer than the stamens	19.4±11.3

When the pistil and stamens were of the same length, a higher percentage of pods was secured from tripped than from untripped

flowers, showing that tripping was effective in increasing the number of pods obtained. The increase was much more pronounced, however, when the pistil was longer than the stamens. This indicates that the relative length of pistil and stamens was an important factor in determining how much natural pollination took place. The importance of relative length of pistil and stamens is also shown by the greater number of pods obtained from untripped flowers with pistil and stamens of the same length. Tripped flowers with the pistil longer than the stamens set less seed than tripped flowers in which the male and female organs were of equal length, but the difference in percentage of pods obtained was only 1.8 times the probable error and need not be considered significant. In any event, a slightly reduced number of pods might result from pollen getting on the pistil in fewer cases when the pistil was longer, even though the flowers were tripped, and does not necessarily imply that plants of the latter type were less efficient seed producers if pollination was once effected. The data indicate that when the pistil and stamens are of equal length, natural self-pollination occurs fairly readily, but that there is very little natural self-pollination when the pistil is longer than the stamens, and relatively few pods are secured unless tripping is practiced.

When a plant with pistil and stamens of the same length was crossed with a plant in which the pistil was longer than the stamens, the F_1 plants were found to possess flowers with pistil and stamens of the same length. F_2 data, shown in Table 3, indicate that the long pistil is inherited as a simple Mendelian recessive.

TABLE 3.—*Observed and expected frequencies in F_2 families of a cross between annual white sweet clover plants (F. P. I. No. 74479) with pistil longer than stamens and with pistil the same length as stamens.*

Cross	Observed		Expected		Dev. in numbers	P. E.	$\frac{\text{Dev.}}{\text{P. E.}}$
	Pistil same length	Pistil longer	Pistil same length	Pistil longer			
3 x 8—A	62	20	61.5	20.5	0.5	±2.64	Less than 1
3 x 8—B	67	21	66.0	22.0	1.0	±2.74	Less than 1
3 x 8—C	151	47	148.5	49.5	2.5	±4.11	Less than 1
Total	280	88	276.0	92.0	4.0	±5.60	Less than 1

SUMMARY

1. In crosses between an annual strain of white-flowered sweet clover and common biennial white sweet clover, the annual habit is dominant over the biennial and a 3:1 ratio is obtained in the F_2 generation.

2. Reciprocal crosses with Hubam sweet clover indicate that, although of different origin, the two annual strains possess the same dominant mutation for the annual habit.

3. A plant is described which was partially annual and partially biennial. This was apparently caused by a dominant somatic mutation, the annual portion being heterozygous for time of flowering.

4. Relative length of pistil and stamens was found to be correlated with the ease of self-pollination. When pistil and stamens are of the same length, self-pollination readily takes place, but when the pistil is longer than the stamens, there is very little self-pollination.

5. The type of flower in which the pistil is longer than the stamens is inherited as a simple recessive.

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NOTES

AN INEXPENSIVE TYPE OF CONSTRUCTION FOR CONCRETE TANKS FOR SOIL INVESTIGATIONS

FIG. 1. Showing method of construction of concrete tanks

FOR use in soils investigations, 50 concrete frames were constructed in the spring of 1933 at Massachusetts State College. These have a concrete bottom, and each is provided with an individual drain (Fig. 1). Thus, each one is a potential lysimeter. At present every fifth frame is provided with means for collecting drainage water.

The inside measurements of the frames are 1 m x 1 m x 0.5 m. The outer walls are 5 cm and the base 10 cm thick. A unique type of construction, worked out in cooperation with Prof. C. I. Gunness of the Department of Agricultural Engineering, was employed, which made the total cost of installation, including excavation, comparatively low—$370. The walls and partitions were cast in molds and were made in the winter when field work could not be done. It was necessary to build a form only for the base, and that consisted of only 2 x 4's and partition strips. The joints were made tight with asphalt roofing cement, and the interior of each tank was given two coats of asphalt paint.

FIG. 2.—Japanese millet growing in concrete tanks at Massachusetts Experiment Station.

A crop of Japanese millet was grown in the frames in 1933 (Fig. 2)

to test the uniformity of soil conditions. The following constants, expressed as percentages of the mean yield, were obtained by Bessel's formula:

	Probable error, single yield	Probable error, mean yield
Treated singly	±4.27	±0.59
Treated by adjacent 2's	±3.93	±0.78
Treated by adjacent 5's	±3.36	±1.06

A. B. BEAUMONT, *Massachusetts State College, Amherst, Mass.*

A SIMPLE METHOD OF THRESHING SINGLE OAT PANICLES

AFTER various methods had been tried with different degrees of success, it has been found recently that single oat panicles may be threshed both rapidly and satisfactorily by hand simply by using a light-weight, close-fitting leather glove. If one is right-handed a glove on the right hand is sufficient. The straw or stem of the panicle is gripped firmly between the thumb and forefinger of the left hand, and the spikelets are stripped from the rachis between the thumb and forefinger of the right hand. If the material is reasonably dry the kernels can be threshed from their glumes satisfactorily simply by rolling and kneeding them between thumb and fingers of the gloved hand.

In stripping, as well as in threshing the seed after stripping, the hands should be held over a grain laboratory pan to prevent loss. After the kernels are threshed they are dropped into the pan and the chaff is blown out by a few puffs of the breath. If some of the spikelets are inclined to remain together, they can usually be separated rather easily by use of both hands. The use of a laboratory pan is recommended as it enables one to pour the threshed seed into envelopes.

Several kinds of gloves have been tried in threshing oats, but only strong leather gloves of light weight have proved satisfactory. Cloth, or part cloth, gloves are unsuitable, as the oat kernels hang to the cloth, endangering mixture, and the chaff penetrates the glove, resulting in irritation to the hands. Furthermore, a light-weight leather glove does not seriously hamper one's using a pencil to label envelopes.

By the use of a glove it was possible for one man to thresh, place in envelopes, and number from 100 to 150 oat panicles per hour—a speed hardly possible with any other method or equipment in general use.—F. A. COFFMAN, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.*

THE TOXICITY OF *CROTALARIA SPECTABILIS* ROTH TO LIVESTOCK AND POULTRY

Crotalaria spectabilis Roth was introduced into the United States a number of years ago by the Bureau of Plant Industry, U. S. Dept. of Agriculture. It is a valuable leguminous cover crop for much of the southeastern states area. The question of its toxicity was not considered, because of its lack of promise as a forage crop, although the genus *Crotalaria* is known to contain species that are toxic, as well as others that are non-toxic.

Chickens brought to E. F. Thomas, formerly assistant veterinarian with the Florida Agricultural Experiment Station, for post-mortem examination in December, 1931, showed lesions that were not typical of any of the ordinary pathological conditions previously encountered. Seeds of *C. spectabilis* were found in the crop and gizzard. Controlled feeding experiments[1] demonstrated conclusively that as few as 80 seeds would kill a hen. Other experiments showed that chickens confined in a yard where this plant was bearing ripe seeds would eat sufficient seeds to kill them.

In another investigation conducted jointly by the Division of Forage Crops and Plant Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Departments of Agronomy and Animal Husbandry of the Florida Agricultural Experiment Station, in which the relative palatabilities of several of the species of *Crotalaria* were being compared in the form of dry roughage, only three cattle (yearlings) out of 19 head, were observed to eat *C. spectabilis* hay in any quantity. These three animals died. It has been seen that small amounts may be taken without actually killing an animal. Three mature cows consumed a total of 12 pounds of the hay in one test without the appearance of any symptoms of poisoning. Two cows were observed to eat some leaves of *C. spectabilis* when the plants were in the early bloom stage without apparent injury.

The most important symptoms of the poisoning were complete loss of appetite, sluggishness, bloody feces, mucous nasal discharge (sometimes bloody), and rapid but weak heart action. The post-mortem lesions include petechial hemorrhages in the subcutaneous and mesenteric fat, lungs, trachea, gall bladder, urinary bladder, and pericardium. Endocarditis, myocarditis, and epicarditis were observed in all three animals. The liver showed fine red mottling. The spleen seemed to be enlarged. The mucous membrane of the abomasum was edematous. The submucosa of the small intestine showed ecchymoses and petechial hemorrhages. Blood and blood clots were present in the lumen of the large intestine.

Final proof of the toxicity of *C. spectabilis* hay to cattle was obtained in December, 1933. A 300-pound steer was drenched over a 4-day period with a total of 9.5 pounds of artifically dried hay that had been ground and suspended in water. Death occurred on the evening of the fourth day. The symptoms and lesions corresponded with those observed in the yearling cattle during the preceding winter.

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[1] THOMAS, E. F. The toxicity of certain species of *Crotalaria* seed for the chicken, quail, turkey, and dove. Jour. Amer. Vet. Med. Assoc., 85: 617–622. 1934.

After this proof of the toxicity of the plant, extracts were prepared from the seeds, the leaves, and the stems, and their toxicity studied. Identical lesions were produced in chickens by the use of whole seeds and by the *extract of the seeds, leaves, or stems*. This demonstrated that the toxic principle had been isolated. The extract had alkaloidal properties.[2] Further experiments then were outlined testing the toxicity of this material with various animals. Rats, rabbits, dogs, chickens, and cattle have proved susceptible to this toxic principle. There is little doubt that any other domestic animal that might eat a sufficient portion of this plant would be poisoned by so doing. Its low palatability, however, makes such cases rare.

Other species under observation during the fall of 1931 and of 1932 included *C. incana* L., *C. intermedia* Kotschy, *C. lanceolota* E. Mey, *C. usaramoensis* Baker, *C. anagyroides* HBK., and *C. grantiana* Harvey, all of which were eaten in considerable amounts and without any indications of harmful effects. *C. striata* D. C., previously accused elsewhere of possessing toxic properties, was not eaten in appreciable quantities on the station farm, but it has been reported eaten with impunity by cattle on a number of farms in Florida.—E. W. THOMAS, W. M. NEAL, and C. F. AHMANN, *Florida Agricultural Experiment Station, Gainesville, Fla.*

COMMENTS ON THE WHOLE WHEAT MEAL FERMENTATION TIME TEST

IN a recent issue of this JOURNAL (Vol. 27, pages 241–250), under the caption, "Observations on the Whole Wheat Meal Fermentation Time Test", Dr. E. G. Bayfield, reports some studies made on the fermentation time test as outlined by the writers and compares it with the Pelshenke method. Both of these tests were designed to evaluate the gluten strength of wheat. Dr. Bayfield attempts to appraise these two procedures by reporting the results of some 46 samples, which would require about one day's work, and finally reaches the conclusion that the Pelshenke procedure is to be preferred because the larger dough balls used by Cutler and Worzella stick to the sides of the beakers.

In 6 years' experience with the whole wheat meal fermentation time test, in which the originators of this test have run over 20,000 separate samples of soft and semi-hard wheats, they have not had one dough ball stick to the side of the beaker. Consequently, Dr. Bayfield's paper has been read and studied with some care and the writers feel obliged to answer it in order to avoid any misunderstanding on the part of readers of the JOURNAL, especially plant breeders.

It should be noted at the outset that the wheat meal fermentation time test and the Pelshenke test are both modifications of the Saunder's test which was reported in the *Journal* of the Institute of Agricultural Botany (Vol. 2, 1928). The writers were the first in America to modify the Saunder's test so that it might be applicable to testing the gluten strength of small plant breeding samples of wheat,

[2]NEAL, W. M., AHMANN, C. F., and RUSOFF, L. L. The isolation and some properties of an alkaloid from *Crotalaria spectabilis* Roth. Paper presented before the Amer. Chem. Soc., St. Petersburg, Fla. March 27, 1934. In press.

while Pelshenke of Halle, Germany, did the same thing in Europe. These investigators, working independently and unknown to each other, discovered and published tests which involved somewhat different procedures.

Dr. Bayfield did not follow either the Cutler-Worzella or the Pelshenke procedures, and consequently, should not expect to obtain results that would correlate with those obtained by the authors of these tests.

The original Pelshenke test includes both a protein content test and a fermentation test for each sample. The gluten quality is then obtained by dividing the "time" by the amount of protein and the resulting figure is designated as "specific protein quality". This is emphasized as an important feature of the Pelshenke test because the end result takes into account both quantity and quality of gluten. Furthermore, Pelshenke derives the 5-gram dough ball by first kneading a 10-gram dough ball and then dividing it into two equal parts. Each of these parts was then placed in a low form, 150-cc beaker in 75 cc of water and held at 32° to 33°C in a fermentation cabinet.

The Cutler-Worzella procedure, on the other hand, involves only the fermentation feature, the protein test not being included, and the results are reported in minutes. Triplicate tests consisting of 10-gram dough balls are made separately in low form, 150-cc beakers in 80 cc of water held at 26.7°C. The writers also recommended the use of a 5-gram and a 3.5-gram dough ball. In using these dough balls, however, the amount of yeast suspension, the size of the beaker, and the amount of water in the bath had to be reduced. Furthermore, a 10% variability rule is observed as a basis of agreement in the results obtained.

In carrying out his tests, Dr. Bayfield departed from one or both of the two procedures he appraises in the following details:

1. Temperature of the water bath and fermentation cabinet.
2. Disregard of the "specific protein quality" number of the Pelshenke test.
3. Proper granulation of the wheat meal.
4. Making the Pelshenke dough ball.
5. Replication of dough ball tests.
6. Non-observance of the 10% variability rule.

Inasmuch as Dr. Bayfield did not follow either the Cutler-Worzella or the Pelshenke procedure in detail his results cannot have any significance as a basis for appraising these two methods.

Once again the authors of the fermentation time test are impelled to caution users of this test, as in former papers, that the test "is not fool-proof and must be conducted according to prescribed methods if a high degree of satisfaction is to be achieved", and that "it will prove a valuable guide to gluten strength when applied with due regard for care and attention to details."

We believe that had Dr. Bayfield followed the prescribed procedure, he like many other experimenters, would have obtained equally satisfactory results.—G. H. CUTLER AND W. W. WORZELLA, *Purdue University Agricultural Experiment Station, Lafayette, Indiana.*

FURTHER COMMENTS ON THE WHOLE WHEAT MEAL FERMENTATION TIME TEST

A pre-publication review of the above note by Professor G. H. Cutler and Dr. W. W. Worzella commenting on "Observations on the Whole Wheat Meal Fermentation Time Test" has been made possible through the courtesy of the Editor of this JOURNAL.

The writer believes that no benefit will result from an extended exchange of opinions unsupported by adequate data, but it is desired to correct any misleading impressions which may possibly result from reading the criticisms by Cutler and Worzella regarding paucity of data. This criticism was also made by Professor Cutler after reveiwing the original manuscript before it was presented for publication in this JOURNAL. The writer, in a personal communication (Jan. 15, 1935) to Professor Cutler, replied that the conclusions were based on some 2,000 tests and not merely on the 46 samples given as examples in the paper published as a preliminary report.

Since then, much additional data have been accumulated. Part of this material has been accepted for publication in *Cereal Chemistry* under the title, "Soft Winter Wheat Studies. IV. Some Factors Producing Variations in Wholemeal 'Time' Data". Furthermore, a collaborative study of the test was undertaken in conjunction with several prominent cereal chemists in the United States and Canada. The resulting report, "A Collaborative Study on the Use of the Wheat Meal 'Time' Test With Hard and Soft Wheats", is now in an advanced stage of publication. These additional data support the earlier conclusions regarding size of dough ball previously presented in this JOURNAL as a preliminary report. In fact, it is believed that a 4-gram dough ball should be used with the 150-cc form beaker and 80 cc of water if the entire range in strength existing in North American wheats is to be tested.—E. G. BAYFIELD, *Ohio Agricultural Experiment Station, Wooster, Ohio.*

BOOK REVIEWS

WEEDS

By W. C. Muenscher. New York: Macmillan Company. 577 pages, illus. 1935. $6.00.

THIS book is a botanical approach to the study of weeds in northern United States, containing keys, descriptions, and well-executed illustrations by which anyone would have no difficulty in identifying a particular weed plant. Included in the list are not only common native plants, but also some cultivated plants which have escaped and become troublesome. A fuller conception of the scope of the book may be gained by mentioning that the horsetails, various ferns, and violets are to be found among the plants listed.

The plants are arranged alphabetically under their scientific names by families, the families being in turn arranged according to botanical phyllogenetic conceptions. Following the scientific and common names come a description of the methods and places of distribution, description of the plant, and means of control.

A chapter on the dissemination and importance of weeds occupies 39 pages; a chapter on weeds of special habitats, as weeds of lawns, pastures, hayfields, gardens, grain fields, cranberry bogs, and rice fields, occupies 13 pages; a chapter on weed control occupies 17 pages; a chapter on chemical weed control occupies 21 pages; 438 pages are devoted to plant descriptions, keys, and specific control measures; and 48 pages are used for glossary, literature, references, and index.

The treatment is accurate, and the book is well-indexed and well-referenced. Unexpected yet helpful bits of information abound, such as a table of plants likely to harbor diseases of common crop plants, a table of poisonous weeds, and weeds used as medicinal plants. It will be found a valuable publication not only by the student and teacher, but also by the extension worker, the farm bureau agent, and the farmer. (H. B. T.)

PLANT LIFE

By D. B. Swingle. New York: D. Van Nostrand Co., XIV + 441 pages, illus. 1935. $3.00.

ALTHOUGH designated as "A Textbook of Botany," this book will be found interesting reading by many. It is designed to fill the need for covering the field of botany in one semester. In presentation of material, the method is used of first arousing the curiosity of the reader and then satisfying it. The entire work is centered around the life processes in plants. The book is adequate and well printed. (H. B. T.)

AGRONOMIC AFFAIRS

AN AMERICAN POTASH INSTITUTE

AMERICAN producers and importers of potash salts announce the organization of the American Potash Institute, Inc., to be established in Washington at an early date with Dr. J. W. Turrentine, formerly in charge of the potash researches of the Bureau of Chemistry and Soils, as President and G. J. Callister, Director of the Agricultural and Scientific Bureau of the N. V. Potash Export My., Inc., as Secretary. The Institute expects to cooperate with federal and state agencies in carrying on research and experimental work in the United States, Canada, and Cuba and with the National Fertilizer Association and other scientific and trade organizations. It is contemplated that branch offices of the Institute will be set up at Atlanta, Ga.; Lafayette, Ind.; San Jose, Calif.; and Hamilton, Ontario.

MEETING OF THE NORTHEASTERN SECTION OF THE SOCIETY

THE following program has been arranged for the summer meeting of the Northeastern Section of the American Society of Agronomy to be held in Maine July 16 to 18.

TUESDAY, JULY 16, HIGHMOOR FARM, MONMOUTH, MAINE

Morning

Visiting experimental plats at Highmoor Farm. (Fertilization and breeding of sweet corn, production of foundation seed potatoes under cloth cages, etc.)

Afternoon

Enroute to University of Maine, Orono, Maine, visiting pasture fertilization plats on the way.

Tour of campus and University Farm.

Banquet and business meeting.

WEDNESDAY, JULY 17

Morning

Enroute to Aroostook Farm, Presque Isle, Maine.

Afternoon

Visiting experimental plats at Aroostook Farm. (Potato fertilization and potato breeding.)

Evening

Meeting of Agronomy Extension Specialists.

THURSDAY, JULY 18

Morning

Visiting experimental plats at Aroostook Farm. (Potato disease control; small grain variety tests.)

Afternoon

Tour of selected farms in Aroostook County, including inspection of farm and truck storage houses.

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GRAPHIC AND QUANTITATIVE COMPARISONS OF LAND TYPES[1]

J. O. VEATCH[2]

MOST descriptions of land surfaces are qualitative. Geographers and geologists have been adept in describing how and why land surfaces differ in their physiognomy, but not in stating to what degree they differ. The need for more precise, or quantitative, descriptions is evident when closely related, or very similar land types are compared, and when land types are being evaluated for some particular use as, for example, a type of farming.

As a consequence of reflections such as the foregoing, and as an attempt to supply a need for quantitative comparisons in connection with recent research in the differentiation of natural land types and in the evaluation of kinds of land in relation to agricultural use, the author has devised a scheme for the graphic comparison of slopes and has developed some additional ideas for comparing land on the basis of the number and areal extent of significant land components.

The scheme for the graphic comparison of topographic components is based upon the premise that any given area of natural land surface has inequalities. There is no part of the earth's land surface that is absolutely flat or entirely devoid of relief. Local differences in elevation may be only a few feet, or at the other extreme, the relief features may be of mountainous magnitude, but in either case the surface area of any tract of land is composed of three parts, *viz.*, (1) the *highland*, relatively level, as the top of a knoll, the crest of a ridge, the table land of a high plateau; (2) the *lowland*, as a valley bottom, a basin, a gentle swale or any other kind of depression; and (3) the *slopes* connecting 1 and 2. The respective percentages of these three components constitute criteria for the evaluation of land; and further, the expression of these components in some quantitative way may be very useful in purely academic comparisons of separate physiographic divisions. The slope component may be subdivided into classes on the basis of range in gradient and the percentage of

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[1]Contribution from the Soils Section, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 215 (new series). Received for publication April 5, 1935.

[2]Research Associate in Soils.

each gradient class determined separately and so furnish additional quantitative data of value. For the purpose of making a graph, the separate slope classes may be integrated and slope expressed as a single line. The number of slope classes and the gradient value assigned to each class may vary in accordance with the purpose of the comparisons and of course should be in harmony with the physiographic type of land surface and local differences in altitude.

Data for constructing graphs can be obtained from contour maps by linear traverse measurements or from actual areal measurement in the event that the latter is practicable. If more accurate and more complete data are desired than can be obtained from the ordinary contour map made on a scale of approximately an inch to the mile with a contour interval of 10 or 20 feet, special field surveys will have to be made. These may consist of linear traverses, run at close intervals, in which the linear extent and frequency of any minor land component may be recorded, or they may be complete areal surveys from which the acreage of any particular land component may be computed on the basis of planimeter measurements.

The illustrative graphs which accompany this paper are based on data obtained by linear measurements from selected U. S. Geological Survey contour maps. The degree to which percentages obtained in this manner represent actual areal extent of the separate components in any given area will depend, of course, upon the interval between the lines of traverse. Four classes of slopes were recognized which were assigned, respectively, average gradient numbers of 5, 10, 20, and 30. Slopes less than 3% in gradient were included as level whether in upland or lowland divisions. In order to expedite the measurement of the slope classes, the contour lines were grouped on the basis of the number per linear mile that fits the range in gradient values assigned to the five classes of slopes. The line of inclination, or the number which represents the integration of the slopes, is obtained by multiplying the percentage number of each class of slope by its gradient average, thence totaling the results and dividing by four.

The following method of plotting the lines was adopted. A square was drawn, a side of which was equal to the total slope percentage distance on the graph, and then a value assigned to its combined right vertical and basal sides equal to one-fourth of the highest gradient value times 100. Thus, if the highest gradient value is 30, the two sides will be 750, and beginning with 0 in the upper right hand corner of the square any integrated slope number can be plotted according to the proportional distance between 0 and 750. For example, a slope value of 375 would be represented by a line drawn from the end of the highland level leg to the lower right hand corner of the square.

The areas illustrated by the graphs were chosen more or less at random but at the same time with a purpose of testing the mechanical practicability of the scheme.

Fig. 1 represents a comparison of glaciated parts of the Allegheny Plateau in southern New York, with unglaciated parts in adjacent northern Pennsylvania. The several areas are fairly comparable in elevation above sea-level. The effect of glaciation is strikingly shown.

The decrease in the length of the slope line and corresponding increase in the percentage of level highland and level valley land is probably in proportion to the degree of glaciation and amount of deposition of drift this being least in the Ithaca quadrangle and greatest in the

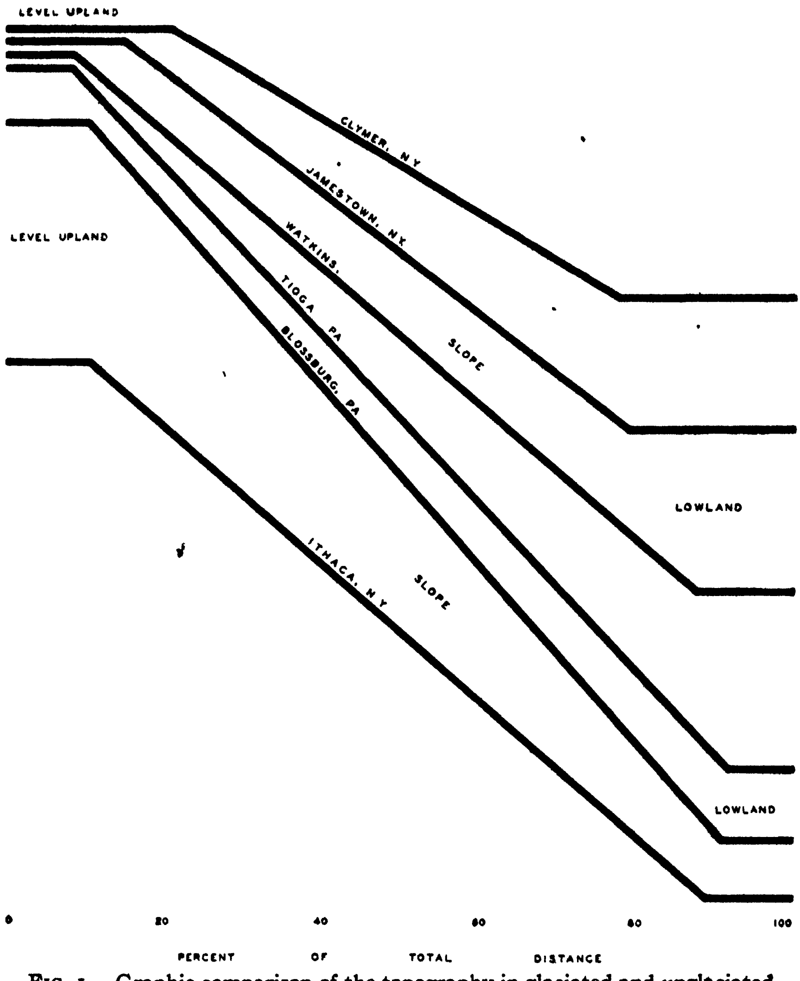

FIG. 1.—Graphic comparison of the topography in glaciated and unglaciated parts of the Allegheny Plateau.

Clymer. Tabulations reveal no great difference in the number of streams and valleys in the glaciated and unglaciated parts of the plateau.

Fig. 2 represents a comparison of glaciated surfaces in regions of crystalline rocks in Maine and in the western part of the Upper Peninsula of Michigan. A very marked contrast in the physiognomy of the two areas is evident. The pre-Glacial topography of the Michigan area was less mountainous and had less relief or the valleys were

more completely filled with drift as compared with the Maine area. A tabulation shows 120 streams per hundred miles of traverse in Maine and only 41 in Michigan. The lowland leg of the Buckfield

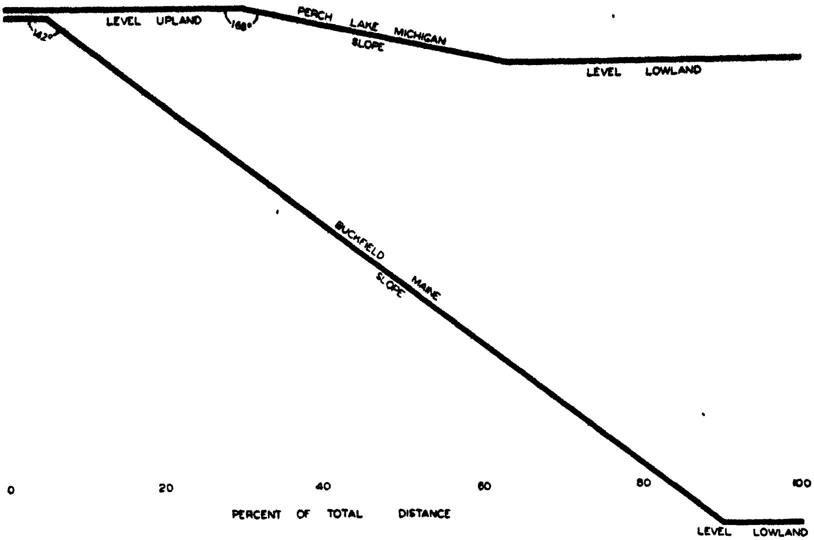

FIG. 2.—Graphic comparison of the topography of areas in Maine and in Michigan.

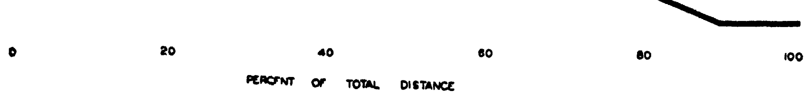

FIG. 3.—Graphic comparison of the topography of areas in the Piedmont Plateau and Coastal Plain of Georgia.

graph is composed almost entirely of stream valley lowland and that of the Perch Lake almost entirely of shallow swampy basins or "muskeg".

Fig. 3 is a comparison of the lower part of the Piedmont Plateau, near Augusta, Georgia, with the central part of the Atlantic Coastal Plain and the lower part of the Coastal Plain near the Georgia-Florida line and a few miles inland from the Atlantic Ocean. The differences in the amounts of level upland and level lowland in the Piedmont and in the Coastal Plain are concisely shown. The number of streams, according to tabulations of frequency, was 132 per hundred miles of traverse in the Piedmont, 59 in the middle Coastal Plain, and 22 in the lower Coastal Plain.

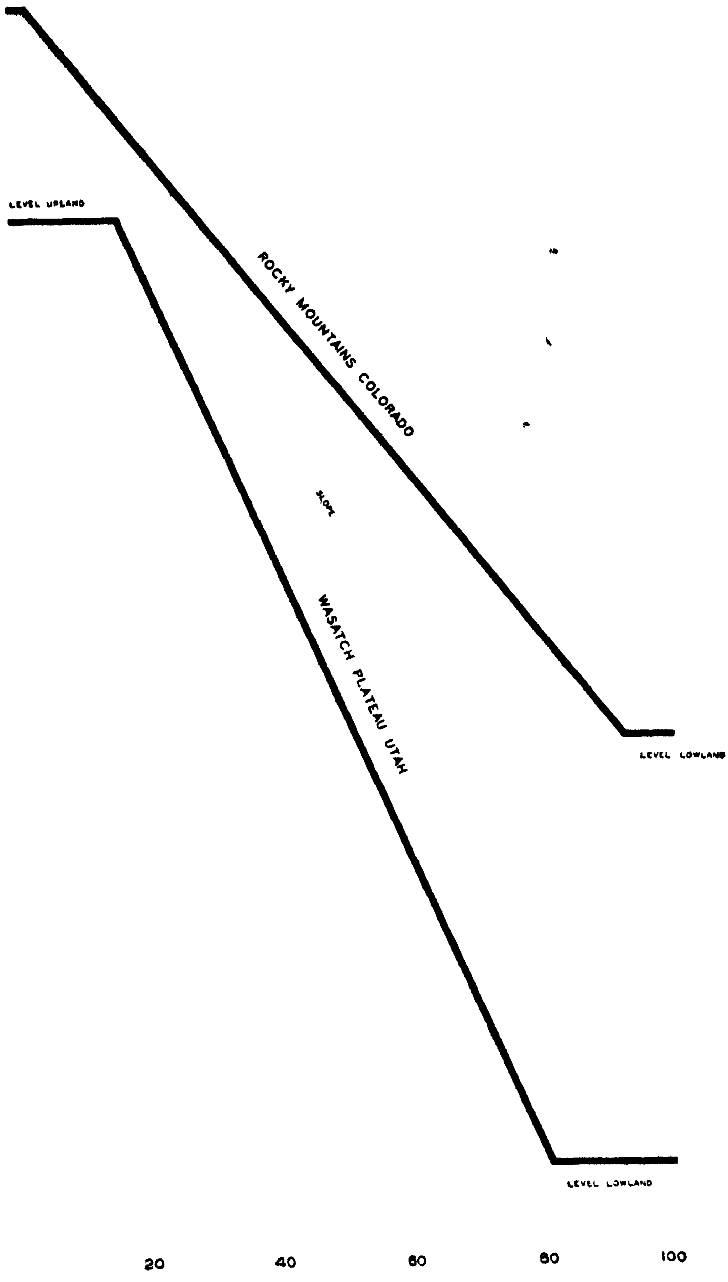

FIG. 4.—Graphic comparison of areas in the Wasatch Plateau, Utah, and in the Rocky Mountains of Colorado.

Fig. 4 is a comparison of an area in the Wasatch Plateau in central Utah with one in the Rocky Mountains in central Colorado. The difference in the two graphs is an expression of the greater maturity of stream dissection, a greater percentage of smoother and less precipitous slopes, and a smaller areal extent of level land on ridge crests in the Rocky Mountain area.

Quantitative data for the comparison of land types may also be expressed in tabular form. The criteria, or particular land components selected for measurement, should be those that have importance whether in the taxonomy of land classification or in relation to economic uses of land. They will not be the same everywhere but will vary according to different natural and economic geographic divisions.

An illustration of a quantitative comparison is given in Table 1.

TABLE 1.—*Quantitative comparisons of selected morainic land types in Michigan.*

Moraine and location	Swamp, % acreage	Swamp frequency	Stream frequency	Lake frequency	Clay land %	Sand, %	Sandy loam %
1. Defiance, Washtenaw Co.	7.5	45	73	4	83	2	7
2. Defiance, Hillsdale Co.	8.5	60	80	8	71	1.5	17
3. Mississinawa, Washtenaw and Jackson Co.	23	119	8	27	1	5	62
4. West Branch, Ogemaw and Roscommon Co.	4	19	9	6	0	81	13

The land data are not complete but even so the table reveals such marked differences that the three separate morainic areas can hardly be considered as the same kind of land except from the point of view of origin. Probably only very minor subtype differences exist between 1 and 2.

Frequency of occurrence of selected features expressed as the number per hundred miles of traverse has both taxonomic and practical significance. The comparative numbers of streams, lakes, and swamps constitute specific criteria throughout the glaciated region of the Great Lakes. The frequency of slopes of more than a 10% gradient and the number of depressions which might constitute "frost pockets" would be significant in the evaluation of land for orchards in southern Michigan.

As a further illustration of the idea of quantitative comparison of land, the comparative amounts of (1) black or dark brown prairie soil, (2) the "gray" prairie soil, (3) the timberland or forest soil, (4) wet upland, and (5) number of streams would comprise the principal data for the differentiation of the major natural land types in the glaciated prairie region of the central United States.

A COMPARISON OF SOME METHODS USED IN EXTRACTING SOIL PHOSPHATES, WITH A PROPOSED NEW METHOD[1]

C. L. WRENSHALL AND R. R. McKIBBIN[2]

THE power of weakly acid solutions to extract a portion of the soil phosphate has been made the basis of a number of methods of estimating the capacity of a soil to supply the phosphorus requirements of growing plants. It is well known that these methods give valuable results, especially when the limit values are carefully worked out for the soil types and climatic zones on which they are used. The results obtained are often highly correlated with the results of field trials, pot tests, and the Neubauer (6)[3] seedling method. The fact that such methods are of value indicates that the readily soluble, inorganic phosphate in the soil constitutes the chief source of phosphorus available to plants.

It is also common knowledge among workers in this field that instances arise in which acid extraction methods give a false impression of the power of a soil to supply phosphorus to crops. This seems especially true for soils of calcareous nature. Thus Das, (1), McGeorge and Breazeale (5), and others have found it necessary to devise other means of detecting phosphorus deficiency in calcareous soils, and Thornton (7), in a recent comparison with the seedling method, found that acid extraction removed too much phosphorus from neutral and calcareous soils.

It was thought that the deficiencies of many or all of the present acid extraction methods might be at least partly due to the fact that they involve extracting the soil with solutions containing large quantities of ions which are relatively rare in the soil solution. In general, the calcium ion is much more abundant in soil water than is either the ammonium or potassium ion, and the sulfate ion is normally the predominating anion. If the ions present have specific effects on the amount of phosphorus extracted, it would seem logical that the ions present in any solution used to extract the fraction of soil phosphorus most available to plants should be those chiefly present in soil solutions.

The present investigation was undertaken with the intention of comparing the power to extract soil phosphate of acid solutions containing calcium ion and sulfate ion with the power of the extracting solution of Truog (8) and that of Lohse and Ruhnke (4). Such a comparison would demonstrate any differences due to the different cations present. Having in mind the idea that the solutions containing calcium ion should more nearly approach natural extracting

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[3]Reference by number is to "Literature Cited", p 518.

conditions in the soil, it was hoped that their use might lead to a better means of characterizing soils on the basis of available phosphorus. Further work, in the form of standardization against field and pot tests, is projected.

EXPERIMENTAL PROCEDURE

Preliminary experiments were directed toward the preparation of sulfuric acid solutions containing calcium sulfate, which would afford proper comparison with the other methods from the standpoint of both intensity and capacity factors of acidity. The following solutions were adopted for use.

1. *$Ca(HSO_4)_2$*.—For direct comparison with the Lohse and Ruhnke extraction: Calcium, 300 p.p.m., sulfate (SO_4), 1,440 p.p.m. (theoretically $Ca(HSO_4)_2$), pH 2.0. The change in the pH value of this solution on extraction of a soil is usually negligible, and in case there is appreciable change it corresponds closely to the change in the pH value of a $KHSO_4$ solution of the same normal concentration and pH.

2. *Quebec solution*.—For direct comparison with Truog's extraction: Calcium, 500 p.p.m., sulfate, 1,270 p.p.m., pH 3.0. This solution contains 1.70 grams of $CaSO_4$ per litre. Saturated $CaSO_4$ contains about 1.76 grams per litre at 0° C (3). Using this solution, the change in pH value during extraction of a soil was found to correspond closely to the change in the pH value of Truog's solution on extraction of the same soil.

Comparisons of the extracting powers of the different solutions were made on a variety of soils. All soil samples were air-dried and screened through a 20-mesh sieve. The phosphate contents of extracts were determined by the Deniges (2) colorimetric method as modified by Truog and Meyer (9). Color comparisons were made in a Kennicott-Campbell-Hurley colorimeter, which has been found very suitable for this work, particularly when the colors were faint. Results have been expressed as p.p.m. of elemental phosphorus in the soil.

All pH determinations were made electrometrically, using the hydrogen electrode and calomel half-cell.

DATA AND DISCUSSION

The extracting power of the $Ca(HSO_4)_2$ solution was compared with that of the $KHSO_4$ solution of Lohse and Ruhnke on a number of soil samples taken from fertilized and unfertilized pasture soils of the brown forest soil type. The extractions with the $Ca(HSO_4)_2$ solution were of five minutes duration for direct comparison with the Lohse and Ruhnke procedure. The results are recorded in Table 1.

These data show that in 5-minute extractions the $Ca(HSO_4)_2$ solution extracted much less phosphate phosphorus than the $KHSO_4$ solution in all cases. This consistent difference could only be attributed to the different action of the potassium and calcium ions, as the solutions were strictly comparable in other respects.

By testing with potassium thiocyanate it was seen that the $KHSO_4$ extracts contained appreciable amounts of ferric iron, and the $Ca(HSO_4)_2$ extracts a slight trace. A test with acidified calcium sulfate solutions of graded pH showed that some ferric iron could be extracted from soils of this type by all solutions of pH 2.60 or less.

A test of the course of extraction of the $KHSO_4$, $Ca(HSO_4)_2$, Truog, and Quebec solutions was made, using soil 5 A. The results are recorded in Table 2, and expressed graphically in Fig. 1.

TABLE 1.—*Comparison of $KHSO_4$ and $Ca(HSO_4)_2$ as extracting agents.*

Soil	P extracted in p.p.m. of soil	
	$KHSO_4$	$Ca(HSO_4)_2$
1 A	25	15
1 B	17	7
1 C	18	7
2 A	56	40
2 B	24	9
2 C	20	6
3 A	38	18
3 B	25	9
3 C	25	5
4 A	39	19
4 B	25	11
4 C	25	8
5 A	53	34
5 B	28	14
5 C	28	9
6 A	52	42
6 B	31	10
6 C	27	9

TABLE 2.—*Influence of duration of extraction on the amount of phosphorus extracted by different solutions from a brown forest soil.*

Duration of extraction in minutes	P extracted in p.p.m. of soil			
	At pH 2.0		At pH 3.0	
	$KHSO_4$	$Ca(HSO_4)_2$	Truog	Quebec
5	50	34	20	17
10	60	42	—	—
15	—	—	25	21
20	78	56	—	—
30	92	67	28	23

These data demonstrate clearly the drastic action of solutions at pH 2.0. In the case of the $KHSO_4$ solution and of the $Ca(HSO_4)_2$ solution sufficient sesquioxides were dissolved in the half-hour extraction to form a very appreciable precipitate when the extracts were neutralized with NH_4OH. Furthermore, it is evident that no distinct fraction of the soil phosphate is dissolved in 5 minutes, nor even in the half-hour extraction, as phosphate is being dissolved at a considerable rate throughout the range of duration studied. It appears that the values obtained on these soils with solutions at pH 2.0 must be very arbitrary.

In the cases of the Truog and Quebec solutions, on the other hand, the rate of extraction of phosphorus falls off rapidly after the first 5

minutes, and after 30 minutes phosphate is being dissolved at a very slow rate. No trace of ferric iron could be detected in these extracts.

The specific action of different ions is also illustrated in these data. Comparing $Ca(HSO_4)_2$ with $KHSO_4$, and Quebec with Truog, it is

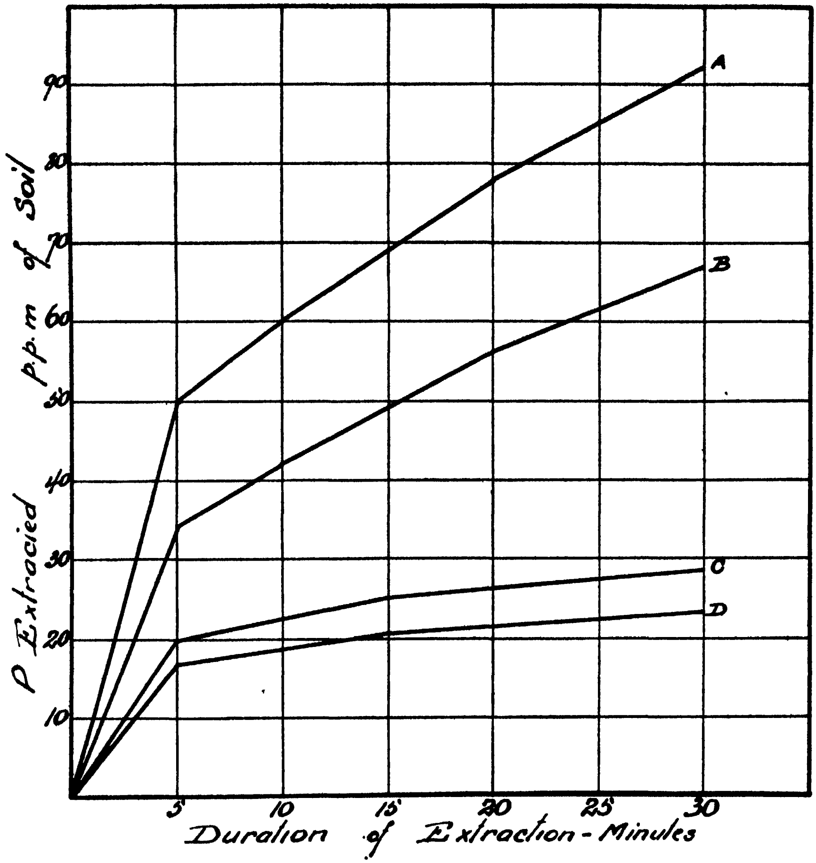

FIG. 1.—Rates of solution of soil phosphate in different solvents.

Key	Solution	Initial pH value	pH value after ½ hour extraction
A	$KHSO_4$	2.00	2.05
B	$Ca(HSO_4)_2$	2.00	2.04
C	$(NH_4)_2SO_4+H_2SO_4$	3.01	3.59
D	$CaSO_4+H_2SO_4$	3.00	3.56

apparent that the solutions containing calcium dissolve less phosphate at all stages of the extractions. The difference between the amounts extracted becomes greater as the extractions proceed in each case; and there is no evidence that a common value will ever be approached. The pH values in each set of comparisons correspond so closely that there seems to be little doubt that the existing differences are due solely to the different actions of the cations present.

A number of soils of widely different nature were extracted with the Truog and Quebec solutions, and the phosphorus determined in the extracts. The results obtained are presented in Table 3 and are

TABLE 3.—*Comparison of Truog and Quebec extractions of a variety of soils.*

Description of soil	Soil desig-nation	P extracted, p.p.m. of soil		% difference (T—Q)100 / T	Final pH of extract		pH of soil
		Truog	Quebec		Truog	Quebec	
Brown earth pasture soils, unfertilized, surface ½ in. layer	R 1	12	12	0	3.50	3.46	5.7
	R 2	17	10	41	3.56	3.60	5.5
	R 3	18	12	33	3.27	3.27	5.6
	R 4	17	15	12	3.44	3.44	5.5
	D 1	8	6	25	3.24	3.24	5.3
	D 2	13	9	31	3.27	3.27	5.4
Brown earth pasture soils, top dressed with superphosphate, surface ½ in. layer	R 5	35	24	31	—	—	5.5
	R 6	28	23	18	—	—	5.6
	R 7	102	80	22	3.53	3.56	5.5
	D 3	15	12	20	—	—	5.4
	D 4	90	53	41	—	—	5.3
	E 1	25	19	24	—	—	5.2
Brown earth cultivated soils, relatively high in lime and nearly neutral, unfertilized, surface layer	A 9	84	47	44	—	—	7.0
	A 13	76	42	45	—	—	6.0
	A 25	80	47	41	—	—	6.5
	A 27	85	50	41	3.20	3.23	6.7
	A 35	80	48	40	3.20	3.25	6.4
	A 37	76	43	43	—	—	6.7
Brown earth calcareous subsoils between 16–24 in.	A C-3	39	6	85	4.12	4.30	8.0
	A D-3	52	13	75	3.38	3.41	7.2
	A E-1	20	2	90	6.28	6.11	7.9
Virgin podsols, A_1 horizon unfertilized	P 1	16	15	6	3.04	3.02	3.0
	P 2	46	40	13	—	—	3.2
	P 3	50	44	12	—	—	4.4
	P 4	45	40	11	—	—	4.3
Cultivated podsols, S 0–8 in., D 16–24 in.	S 4	23	20	13	3.10	3.08	5.4
	D 4	6	5	17	3.22	3.20	5.2
Unfertilized black muck, A 0–12 in., B 12–24 in.	60 A	15	9	40	4.70	4.65	6.3
	109 A	15	14	7	—	—	5.7
	56 A	35	35	0	—	—	3.6
	56 B	10	11	—10	—	—	3.8
	95 A	16	13	19	3.56	3.42	6.6
	35 A	7	11	—57	—	—	4.2
	35 B	5	9	—80	3.83	3.64	5.1
Fertilized black muck, A 0–12 in., B 12–24 in.	C 1 A	112	98	13	—	—	6.7
	C 1 B	18	21	—17	—	—	6.1
	C 2 A	196	185	6	—	—	6.2
	C 2 B	15	15	0	—	—	6.5
	C 3 A	490	430	12	—	—	7.2
	C 3 B	86	92	—7	—	—	6.7
	C 4 A	260	200	23	5.20	5.23	7.0
	C 4 B	32	34	—6	—	—	6.5

grouped according to the nature of the soils. The pH values of the soils, the percentage difference between the phosphorus results, and, in a number of cases, the final pH values of the extracts are also included in the table. Percentage difference between the results by the two methods was calculated thus:

$$\text{Percentage difference} = \frac{(\text{Truog result} - \text{Quebec result})\ 100}{\text{Truog result}}.$$

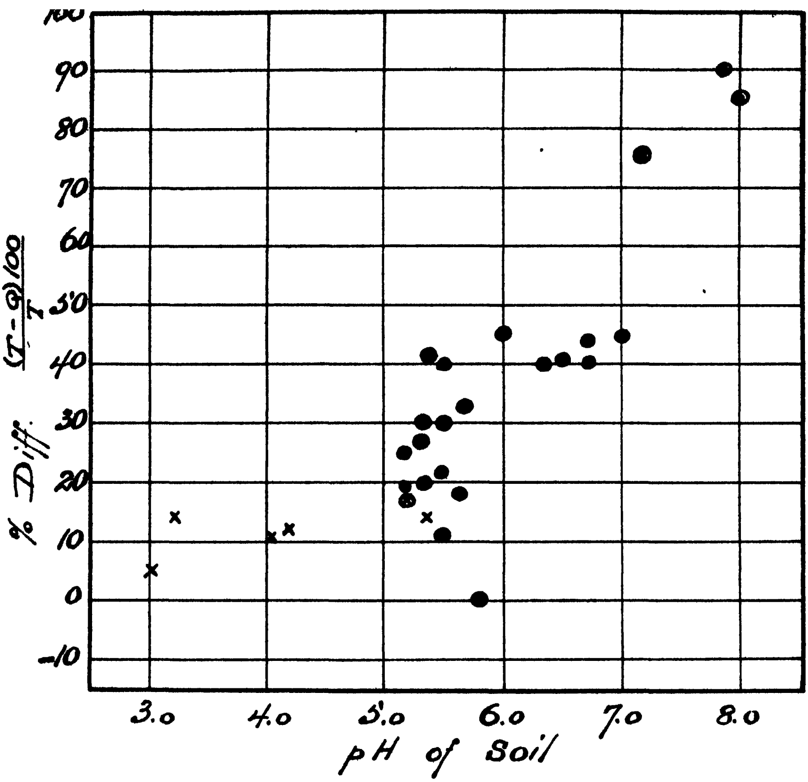

FIG. 2.—The relation of the percentage difference between Truog and Quebec extraction of phosphate and the reaction of inorganic soils. ● brown forest soil; x podsol. Encircling indicates subsoil.

In Fig. 2 the percentage difference between results is plotted against the pH of the soil for the soils of inorganic nature, that is, the brown forest soil and podsol samples.

Considering the data presented in Table 3, it is evident that the results of the two methods are closely related, showing covariance throughout. However, a fairly consistent difference is also evident. In general, the Quebec solution, containing calcium, extracts less phosphate than the Truog solution. This is especially true for the inorganic soils. From a practical standpoint, the actual differences

between the results of the two methods are of apparent significant magnitude in relatively few cases.

The information presented in Fig. 2 gives a fairly definite indication that the percentage difference between the results of the two methods tends to be a function of the reaction of the soil. The percentage differences tend to be small for very acid soils and to increase markedly for soils of higher pH values. It may be that this is because reaction is associated with calcium content in these soils.

Inspection of the percentage differences obtained for unfertilized and fertilized muck soils fails to reveal a similar well-defined relation to soil pH value. The percentage differences appear to be widely variable, and the Quebec solution extracts as much as or more phosphorus than the Truog in about half the cases, notably the subsoil samples. Actual differences in the results obtained on these soils would scarcely influence their characterization as regards available phosphorus. It should be pointed out, however, that the Truog extracts of these soils were discolored, in some cases sufficiently so to make the colorimetric determination very difficult and uncertain, whereas the Quebec method extraction gave water-clear to faintly tinted extracts. This points to another important difference in the action of calcium and ammonium ions, probably on the organic matter. For muck soils, in this respect, the Quebec solution is superior from a practical standpoint.

Comparing the extraction of inorganic soils by comparably acid solutions containing ammonium and calcium ions, respectively, it appears that the calcium-containing solution tends to extract less phosphorus, and that the percentage differences increase with increasing pH values of the soils. Significant actual differences between the amounts extracted are rare for acid soils but rather prevalent in the case of neutral and calcareous soils. Thus, the extraction with the Quebec solution containing calcium and sulfate ions, which is perhaps more closely related to natural soil conditions, may provide a truer estimate of the phosphate in the soil which is actually available to plants. It is hoped that further investigation may provide information concerning this matter.

SUMMARY

Differences in the extracting powers of comparable solutions of $KHSO_4$ and $Ca(HSO_4)_2$ and of comparable solutions containing $(NH_4)_2SO_4$ and $CaSO_4$, have been demonstrated. The cations present affect the solubility of soil phosphates.

The drastic action of solutions at pH 2.0 has been shown.

The dependence of the difference in the extracting power of acid $(NH_4)_2SO_4$ and acid $CaSO_4$ solutions upon soil pH values or associated properties has been indicated.

The probable advantages of extraction with a solution containing calcium and sulfate ions have been pointed out.

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A COMPARISON OF GLASS AND QUINHYDRONE ELECTRODES FOR DETERMINING THE pH OF SOME IOWA SOILS: II. THE VARIABILITY OF RESULTS[1]

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IN the first paper of this series (1)[3], results were presented of experiments conducted to determine the suitability of different types of glass electrodes for measuring the pH of soils. It was found that similar results were obtained with each of the four types of glass electrodes studied, and that the variability in pH of replicate samples of soil was extremely small with each type of glass electrode. The modified bulb, silver-silver chloride type of glass electrode, however, was found most practicable and desirable because of its ease of construction, strength, durability, and also because of the simplicity of keeping it in proper condition for use. Several glass electrodes of the modified bulb type constructed from one stock of glass were found, in the main, to function similarly, and the data indicated that these electrodes may be depended upon to give accurate results.

The next problem in the comparison of glass and quinhydrone electrodes was to determine the normal variation of results of pH determinations made by the two methods. It seemed desirable also to determine, for the soils under observation, the nature and magnitude of the "QH error" and the "QH electrode error" by means of the glass electrode. The data obtained in these studies are presented in this paper.

EXPERIMENTAL PROCEDURE

The modified bulb, silver-silver chloride type of glass electrode, and the ordinary type of platinum electrode with quinhydrone were employed in making the pH determinations in this study. A vacuum tube amplifying unit, constructed according to Goodhue and described in the first paper of this series (1), was used in making the measurements. The voltage readings given by the electrodes were calculated to pH by the Youden and Dobroscky (4) method.

In the study five types of soil were employed, namely, Tama silt loam, Grundy silt loam, Shelby loam, Marshall silt loam, and Carrington loam. A 30.0-gram sample of soil was placed in a 150-cc extraction flask and mixed with 75 cc of CO_2-free distilled water. The mixture was shaken for 1 minute, allowed to stand for 2 hours, and then the supernatant liquid was poured into a special'y constructed U-shaped tube and the glass electrode introduced into the liquid. The electrode was so adjusted that the surface of the liquid inside the electrode was level with the surface of the liquid outside. The KCl-agar bridge making contact with the calomel half-cell was then introduced into the liquid and the potential determined. After the pH of the supernatant liquid was determined with the glass

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[3]Figures in parenthesis refer to "Literature Cited," p 525.

electrode, 0.2 to 0.4 gram of quinhydrone was added and shaken for 15 seconds after which the pH was determined with the quinhydrone electrode.

VARIABILITY OF RESULTS

In order to determine the normal variation of the results obtained by the quinhydrone and glass electrodes, determinations were made on 25 samples of each of the five soils studied, these samples being taken from a large uniform sample of each soil which had been screened and thoroughly mixed. The results obtained are shown in Table 1. A statistical analysis of the results showing the range of variation and the standard deviation is shown in Table 2.

TABLE 1.—*The pH of 25 samples of each of five soils determined by the glass and quinhydrone electrodes.*

No.	Carrington loam		Tama silt loam		Marshall silt loam		Grundy silt loam		Shelby loam	
	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.
1	5.18	5.23	4.98	4.94	—	—	5.40	5.47	5.92	5.99
2	5.16	5.25	4.96	4.98	—	—	5.37	5.45	5.91	5.94
3	5.18	5.25	4.94	5.06	7.55	7.26	5.35	5.50	5.89	5.92
4	5.18	5.23	4.93	5.03	7.55	7.40	5.35	5.48	5.87	5.97
5	5.20	5.23	4.98	5.06	7.43	7.12	5.33	5.45	5.87	5.96
6	5.20	5.23	4.96	5.03	7.41	7.34	5.33	5.45	5.91	5.94
7	5.15	5.23	4.94	4.99	7.43	7.16	5.35	5.45	5.87	5.96
8	5.13	5.25	4.96	5.03	7.46	7.24	5.43	5.42	5.82	5.96
9	5.06	5.23	4.96	5.03	7.43	7.18	5.37	5.40	5.82	5.94
10	5.18	5.23	4.96	5.04	7.45	7.14	5.35	5.40	5.87	5.92
11	5.06	5.21	4.99	5.06	7.45	7.29	5.35	5.43	5.91	5.94
12	5.08	5.20	4.96	4.94	7.45	7.26	5.33	5.43	5.84	5.89
13	5.08	5.21	4.98	5.03	7.45	7.07	5.35	5.45	5.82	5.91
14	5.08	5.20	4.98	5.01	7.45	7.07	5.35	5.43	5.82	5.87
15	5.03	5.21	4.96	5.03	7.41	7.18	5.37	5.48	5.82	5.89
16	5.09	5.21	4.98	5.04	7.41	7.14	5.38	5.47	5.86	5.92
17	5.09	5.23	4.98	5.03	7.33	7.11	5.37	5.47	5.84	5.96
18	5.06	5.16	4.98	5.04	7.40	7.18	5.35	5.48	5.81	5.89
19	5.11	5.23	4.96	5.03	7.40	7.26	5.35	5.47	5.82	5.94
20	5.11	5.18	4.96	5.04	7.43	7.21	5.35	5.45	5.75	5.96
21	5.09	5.23	4.98	5.03	7.33	7.23	5.37	5.47	5.77	5.81
22	5.13	5.23	4.94	5.04	7.48	7.21	5.31	5.43	5.79	5.89
23	5.09	5.21	4.94	5.03	7.45	7.04	5.37	5.45	5.77	5.89
24	5.09	5.11	4.96	5.03	7.46	7.14	5.35	5.45	5.82	5.89
25	5.09	5.18	4.98	5.04	7.50	7.16	5.33	5.47	5.84	5.92
Mean	5.12	5.21	4.96	5.02	7.44	7.19	5.36	5.45	5.84	5.92

It is evident from the data that some variation between samples occurred, but the total range of variation in pH, determined by the glass electrode, was within 0.06 pH for the 25 samples of Tama silt loam. It is also shown by the standard deviation that two-thirds of the determinations on this soil gave results which varied within 0.017 pH above or below the mean. The data secured with other soils varied

TABLE 2.—*Statistical analysis of the variations in the pH of 25 samples of each of five soils.*

Soil type	Glass electrode			Quinhydrone electrode		
	Mean pH	Range	Standard deviation	Mean pH	Range	Standard deviation
Tama silt loam.........	4.96	0.06	0.017	5.02	0.12	0.031
Carrington loam........	5.12	0.17	0.051	5.21	0.14	0.031
Grundy silt loam.......	5.36	0.12	0.022	5.45	0.10	0.035
Shelby loam...........	5.84	0.17	0.046	5.92	0.18	0.039
Marshall silt loam......	7.44	0.22	0.047	7.20	0.36	0.089

slightly more than this and were most variable in the case of the Marshall silt loam, where the range of variation was 0.22 pH. Even with this soil, however, the standard deviation was not large, being only 0.047 pH.

The mean pH values obtained with the quinhydrone electrode were somewhat higher with most soils than those obtained with the glass electrode. The significance of this point will be discussed later. The total range of variation of the results obtained with the quinhydrone electrode for Tama silt loam was within 0.12 pH, and two-thirds of the results varied within 0.031 pH above or below the mean as indicated by the standard deviation. As was the case with the glass electrode, the data obtained with other soils varied slightly more than this. The Marshall silt loam gave the most variable results, the range of variation being 0.36 pH and the standard deviation being 0.089 pH.

It appears that the variability of the results obtained with the glass and quinhydrone electrodes is only slightly different for the various acid soils. In the case of the basic Marshall silt loam, however, there was somewhat less variability in the results obtained with the glass than with the quinhydrone electrode. It would seem, therefore, that the glass electrode is as reliable as the quinhydrone electrode for determining the pH value of soils.

THE "QH" AND "QH ELECTRODE" ERRORS

In the next experiment, in which the "QH error" and the "QH electrode error" were determined, the soils were prepared for analysis in the same manner as in the previous experiment. The pH determinations were made on the soil suspension in this case, however, instead of on the supernatant liquid. A glass and a quinhydrone electrode were each fitted into a rubber stopper so that determinations could be made by either electrode at any time. The measurements were made at intervals of 0.5, 2.0, 5.0, 10.0, and 20.0 minutes.

The "QH error" has been defined by Naftel (2) as the difference between the pH value of the soil suspension when determined by the glass electrode and the pH value of a suspension of the same soil when determined in the same way after the addition of quinhydrone. The "QH electrode error" is defined as the difference in the pH value determined by the glass electrode after adding quinhydrone and the

pH value of the same soil suspension determined by the quinhydrone electrode at the same time.

The "QH" and "QH electrode" errors obtained from this study are shown in Table 3. In making the determinations it was found that where the glass electrode was used without quinhydrone in the soil suspensions the pH readings varied somewhat at different intervals of time. There was little or no change in the pH of the Tama soil, a slight increase in the pH of the Shelby soil, and a slight decrease in the pH of the Carrington, Grundy, and Marshall soils. The maximum change occurred in the Marshall silt loam where the pH decreased 0.17 in 20 minutes. The largest change in pH occurred, in all cases, during the first 2 minutes after immersion of the electrode in the soil suspension.

TABLE 3.—*The "QH error" and the "QH electrode error" in the pH determinations on five soils.*

Time in min.	Tama silt loam		Carrington loam		Shelby loam		Grundy silt loam		Marshall silt loam	
	"QH"	"QH E"	"QH"	"QH E"	"QH"	"QH E"	"QH"	"QH E"	"QH"	"QH E"
	0.2 gram Quinhydrone Added									
0.5	+0.07	-0.04	+0.12	+0.06	+0.26	+0.01	+0.07	+0.03	+0.06	-0.13
2.0	+0.09	-0.01	+0.17	0.00	+0.21	-0.01	+0.11	-0.06	+0.09	-0.15
5.0	+0.12	-0.05	+0.22	-0.03	+0.23	-0.07	+0.03	+0.03	+0.07	-0.11
10.0	+0.14	-0.05	+0.19	-0.03	+0.22	-0.08	+0.08	-0.01	+0.08	-0.06
20.0	+0.17	-0.07	+0.21	-0.04	+0.10	-0.01	+0.08	-0.01	-0.06	+0.03
	0.45 gram Quinhydrone Added									
0.5	+0.16	-0.02	+0.11	+0.05	+0.27	+0.01	+0.13	+0.04	+0.01	-0.09
2.0	+0.14	+0.01	+0.19	+0.02	+0.24	0.00	+0.09	+0.03	+0.06	-0.10
5.0	+0.11	0.00	+0.16	+0.02	+0.21	+0.02	+0.06	+0.01	+0.02	-0.07
10.0	+0.13		+0.16	+0.01	+0.21	-0.04	+0.09	-0.03	+0.01	-0.01
20.0	+0.15	-0.01	+0.19	+0.03	+0.14	-0.02	+0.07	-0.01	-0.05	+0.03
	0.90 gram Quinhydrone Added									
0.5	+0.13	0.00	+0.18	-0.01	+0.31	-0.04	+0.12	+0.03	0.00	-0.09
2.0	+0.13	0.00	+0.24	-0.02	+0.23	0.00	+0.13	-0.08	+0.05	-0.09
5.0	+0.15	-0.07	+0.17	+0.03	+0.20	0.00	+0.12	-0.10	+0.03	-0.07
10.0	+0.15	-0.06	+0.16	-0.01	+0.17	+0.01	+0.11	-0.06	+0.06	-0.06
20.0	+0.16	-0.04	+0.20	-0.01	+0.13	-0.01	+0.09	-0.07	0.00	-0.02

It was also found that the addition of quinhydrone to the soil suspension increased the pH when determined by the glass electrode. The change in pH varied from 0.06 to 0.26 for the different soils, the smallest change occurring in the Marshall silt loam and the largest change in the Shelby loam. There seemed to be little or no difference in the amount of change exerted by the different amounts of quinhydrone employed in this experiment. Apparently the smallest amount added, 0.2 gram, was sufficient to bring about the maximum change. The most rapid change in pH occurred immediately after the quinhydrone was added to the soil suspension. During the next 20 minutes there was also some change in the pH of the soil suspension, but this change was presumably of little consequence as compared with the initial change induced upon the addition of the quinhydrone.

Similar results were obtained when the quinhydrone electrode was employed. There was an increase in the pH values of the soil suspensions after the addition of the quinhydrone when determined by the quinhydrone electrode and compared with the original pH determinations made on the soil suspensions with the glass electrode in the absence of quinhydrone. It is concluded, therefore, that the addition of quinhydrone to these soils changed to a slight extent the observed potentials obtained with the glass and quinhydrone electrodes. These conclusions are in agreement with those of Naftel (2), and Naftel, Schollenberger, and Bradfield (3).

Appreciable amounts of manganese dioxide in soils are known to change the pH in the presence of quinhydrone. It is possible that the soils studied here contained sufficient amounts of this compound to produce the changes observed, but apparently the amounts were not excessive as in the case of certain soils reported by Naftel (2). These soils may, therefore, be grouped with those of Naftel giving fair results with the quinhydrone electrode, and it is concluded that the quinhydrone electrode may be used to determine the pH of these and similar soils without serious error.

Certain investigators have attributed the erroneous results obtained by the quinhydrone electrode method to the improper functioning of the electrode itself. In order to determine whether or not this is the case an additional measurement of the pH of the soil suspensions containing quinhydrone was made with the quinhydrone electrode immediately after the pH was determined with the glass electrode. As was stated above, the difference in the pH readings obtained by these two electrodes is considered as the "QH electrode error". The results obtained in these tests are shown in Table 3. It is obvious that there was very little difference in the results obtained with the glass and quinhydrone electrodes under these conditions, and that the "QH electrode error", determined in this manner, is very little if any larger than the normal variation that may be expected with replicate determinations. Hence, it would seem that the "QH electrode error" for these soils is of little or no consequence. This is in agreement with Naftel's conclusions (2).

CHANGES IN ELECTRODE POTENTIALS

In these and other experiments it was observed that the pH, when determined by either the glass or quinhydrone electrodes, changed somewhat with time. This change has frequently been referred to as a drift in potential. There has been some question whether or not this drift is due to an actual change in the hydrogen-ion concentration of the soil or to a change in the potentials of the electrode used. It was considered desirable, therefore, to check the potentials of the electrodes in a potassium acid phthalate buffer solution of pH 3.97 before and after the electrodes were suspended in a soil solution for 20 minutes. The results of this study are given in Table 4. It may be observed that the potential of the glass electrode changed somewhat during the 20 minutes the electrode was in contact with the soil suspensions. These changes varied from 0.001 to 0.0036 millivolt for the various soils and under the different conditions studied. The average

TABLE 4.—*Glass and quinhydrone electrode potentials in millivolts before and after immersion in soil suspensions for 20 minutes.*

Soil type	QH added, grams														
	None			0.1			0.2			0.45			0.90		
	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
	Glass Electrode														
Carrington	0.1488	0.1491	0.0003	0.1474	0.1451	0.0023	0.1510	0.1516	0.0006	0.1469	0.1457	0.0012	0.1439	0.1443	0.0004
Grundy	0.1499	0.1500	0.0001	0.1517	0.1482	0.0035	0.1488	0.1476	0.0012	0.1469	0.1478	0.0009	0.1492	0.1486	0.0006
Tama	0.1559	0.1523	0.0036	0.1499	0.1490	0.0009	0.1521	0.1511	0.0010	0.1485	0.1504	0.0019	0.1490	0.1489	0.0001
Shelby	0.1490	0.1482	0.0008	0.1534	0.1511	0.0023	0.1509	0.1489	0.0020	0.1490	0.1457	0.0033	0.1479	0.1452	0.0027
Marshall	0.1249	0.1253	0.0004	0.1201	0.1179	0.0022	0.1205	0.1190	0.0015	0.1209	0.1208	0.0001	0.1204	0.1201	0.0003
	Quinhydrone Electrode														
Carrington	—	—	—	0.2162	0.2158	0.0004	0.2168	0.2169	0.0001	0.2165	0.2165	0.0000	0.2160	0.2159	0.0001
Grundy	—	—	—	0.2189	0.2185	0.0004	0.2197	0.2198	0.0001	0.2181	0.2179	0.0002	0.2176	0.2173	0.0003
Tama	—	—	—	0.2201	0.2199	0.0002	0.2212	0.2188	0.0024	0.2182	0.2181	0.0001	0.2189	0.2181	0.0008
Shelby	—	—	—	0.2168	0.2174	0.0006	0.2169	0.2161	0.0008	0.2176	·0.2179	0.0003	0.2178	0.2176	0.0002
Marshall	—	—	—	0.2131	0.2129	0.0002	0.2133	0.2135	0.0002	0.2131	0.2130	0.0001	0.2133	0.2130	0.0003

change in potential of the quinhydrone electrode was somewhat smaller than that for the glass electrode, the largest change being 0.0024 millivolt. It may be of interest to note that 0.0059 millivolt is necessary to make a change of 0.1 pH.

Although the changes in the potentials of the glass electrode, when checked against a standard buffer solution before and after use, were comparatively small, it was considered a desirable precautionary measure to check the potentials of this electrode at frequent intervals while it is being employed for determining the pH of soils. It may also be desirable to check the potentials of the quinhydrone electrode in the same manner, but apparently this is not so important with the quinhydrone electrode as it is with the glass electrode.

SUMMARY AND CONCLUSIONS

1. The variability of the results obtained by the use of the glass and quinhydrone electrodes for determining the pH of some Iowa soils was studied, and the nature and magnitude of the "QH error" and the "QH electrode error" were determined by means of the glass electrode. The potentials of the glass and quinhydrone electrodes were checked in a potassium acid phthalate buffer solution before and after the electrodes were suspended in a soil suspension for 20 minutes.

2. The variability in the pH of 25 samples of different soils, when determined by either the glass or the quinhydrone electrode, was comparatively small and presumably of little practical consequence.

3. The addition of quinhydrone to the soil suspension increased the pH of each soil slightly when determined by the glass or quinhydrone electrodes. This change in pH resulting from the addition of quinhydrone to the soil is referred to as the "QH error". This error was scarcely large enough to make the quinhydrone electrode method unreliable for determining the pH of the soils studied.

4. The glass and quinhydrone electrodes gave similar results when employed to determine the pH of soil suspensions containing quinhydrone. The "QH electrode error", therefore, is of little or no consequence in the soils studied.

5. The potentials of the glass and quinhydrone electrodes change somewhat during the process of pH determinations. It is desirable. therefore, to check these electrodes against a known buffer solution at frequent intervals.

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THE COMPARATIVE ROOT DEVELOPMENT OF REGIONAL TYPES OF CORN[1]

RALPH M. WEIHING[2]

THE root systems of regional types of corn (*Zea Mays* L.) differing materially aboveground were studied to discover any inherent morphological differences. Investigations during the last four decades by Hays (1),[3] Ten Eyck (6), and Weaver (8) have added much to our general knowledge of the root system of corn but did not concern the comparative development of divergent vegetative types. In other species definite differences in root systems have been shown by Mohammad and Deshpande (5) with chillies, by Venkatraman and Vittal (7) with sugar cane seedlings, and by Jean (2) with peas. This suggests their possible existence among divergent types of corn.

Accordingly, varieties differing materially in mature plant height, number and area of leaves, earliness of maturity, etc., when grown at Lincoln, Nebr., were assembled from various règions. A natural classification grouped the varieties representative of corn adapted to northern, central, and southern areas of the United States into small, medium, and large vegetative types, respectively. The gross morphology of the root systems was studied under normal field conditions, while root weight and volume were determined under pot culture.

EXPERIMENTAL PROCEDURE

GROWTH CONDITIONS AND SEED SOURCES

The various types were grown comparably at Lincoln in 1933 under the same environmental conditions in order that any stalk and root differences between them might be attributed to heritable behavior. The soil was Carrington silt loam which is typical of extensive areas in which corn is grown. Plant development was rather normal as indicated by a grain yield of 43 bushels per acre from the Krug variety grown in this experiment as compared with a 33-year average of 46 bushels for standard varieties on the Experiment Station farm.

The small varieties, Rustler from North Dakota and Minnesota 13 from western Nebraska; the medium large varieties, Krug from southeastern Nebraska, Pride of Saline from Kansas, and Hulsart Yellow Dent from New Jersey; and the large varieties, Reese Drought Resister from Texas and Mexican June from Arizona, were, respectively, characteristic of corn grown in northern, central, and southern areas of the United States. All varieties were dent corn well adapted to the regions from which they came.

CULTURAL METHODS

Hays (1), Ten Eyck (6), and Weaver (8) have found the maximum spread of the main roots of corn to be approximately 3.5 feet in all directions from the

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[3]Figures in parenthesis refer to "Literature Cited," p. 537.

stalk. Accordingly, competition, which might modify normal heritable root behavior, was largely eliminated in these experiments by growing the plants singly in hills spaced 7 feet apart. The field was tilled with a sweep cultivator deep enough to destroy the weeds without injuring the main roots of the corn. All tillers were carefully removed at an early stage in order to eliminate this variable factor.

To facilitate determinations of the volume and the weight of roots, one representative variety of each type was grown to maturity in triplicated pots 16 x 36 inches in size. The pots were filled with fertile Carrington silt loam soil which had been screened to remove organic debris. Water and fertilizers were applied in sufficient quantities to permit normal aerial development. Any moisture draining from the pots was collected and returned to the one from which it percolated. One plant was grown per pot.

ROOT EXAMINATIONS

The main roots of the secondary root system of plants grown in the field were studied periodically from the seedling to the mature stage. These roots in contrast

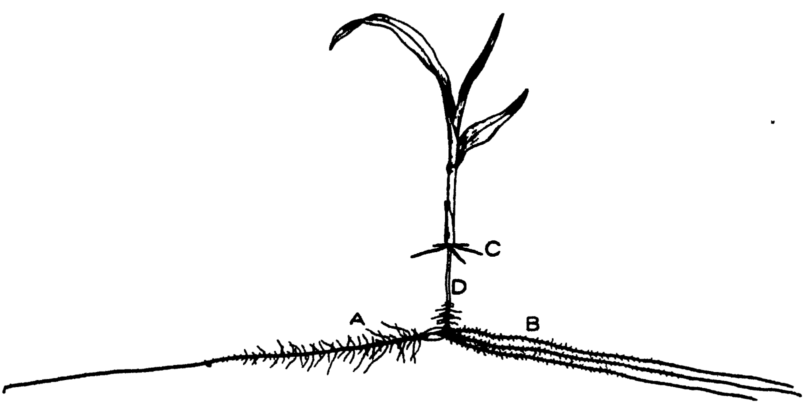

FIG. 1.—The primary and secondary root systems of a representative corn plant with three expanded leaves. A and B, the primary and seminal roots, respectively, of the primary root system. C, initial whorl of roots of the secondary root system. Approximately 80 additional roots are formed later from the next eight higher nodes of corn suitable to southeastern Nebraska. D, epicotyl.

to those of the primary system increase in number after the seedling stage, as shown in Fig. 1, and in dent corn are ultimately 15 to 20 times as numerous. Although the primary root system may live to maturity and penetrate 5 to 6 feet deep, it was frequently dead on many normal-appearing plants shortly after the appearance of the secondary root system. A study of the primary root system was not included in these investigations because its number of main roots is constant after the seedling stage and because it comprises such a small part of the entire number of roots of older plants that variations within it would seem to have little importance.

The roots of a representative plant of each variety were examined 2, 4, 6, 8, and 12 weeks after planting. The small varieties were mature at the end of the twelfth week. Subsequently, an additional examination was made of the larger varieties as they matured. The root determinations were accomplished in the

main according to technic described by Weaver (8). A trench was dug along one side of the plant. The roots were exposed, singly, by the use of a shovel, pick, and ice pick. After obtaining the desired data, each root was removed to facilitate the tracing of others. All of the main roots were traced for plants excavated 2 and

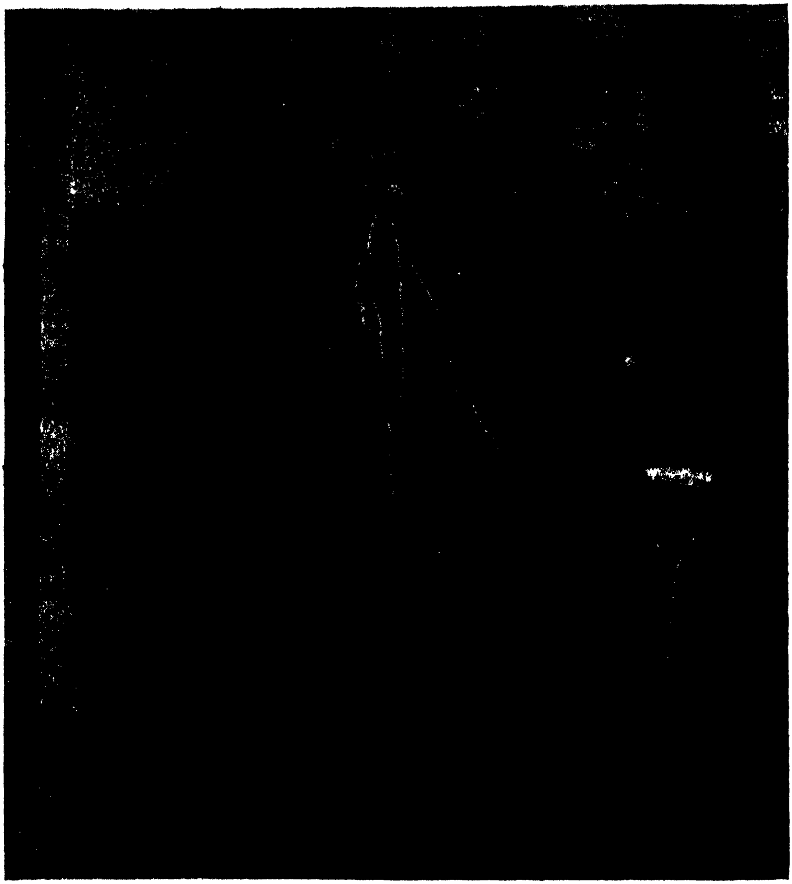

FIG. 2.—A mature plant of the variety Mexican June with its root system partially uncovered.

4 weeks after planting. Thereafter, only half of them, or those located on one side of a median line through the plant, were examined. Fig. 2 shows a few roots of a mature plant partially uncovered.

For the plants grown in pots, the soil was slowly washed from the roots at maturity. Any loose root fragments were caught in a screen through which all drainage water passed. Fig. 3 shows a root system after about half of the soil had been removed. Root volumes by the water displacement method and moisture-free weights were obtained.

PRESENTATION OF DATA

The varieties used in this study were selected to represent small, medium, and large types. Examination of the data for aboveground characters of mature plants substantiated this grouping. As it was not the purpose to study specific varieties, only the mean data for each type are presented.

DIFFERENCES BETWEEN TYPES AT MATURITY

STALK CHARACTERS

The data in Table 1 show that three distinct types of corn differing in vegetative size, as desired, were grown. Comparing the small, medium, and large types, the respective values for various plant characters were as follows: (a) Number of days from planting to tasseling 50, 65, and 79; (b) number of days from planting to ripening 88, 112, and 129; (c) stalk height 55, 87, and 92 inches; (d) number of leaves from nodes aboveground 12, 17, and 20; (e) leaf area 658, 1,412, and 1,747 square inches; (f) stalk diameter 22, 27, and 32 mm; (g) moisture-free fodder weights per plant 248, 380, and 622 grams; and (h) acre yield of stover 1,766, 3,628, and 4,458 pounds. The grain yield was greatest for the medium type as was to be expected for varieties most nearly adapted at Lincoln.

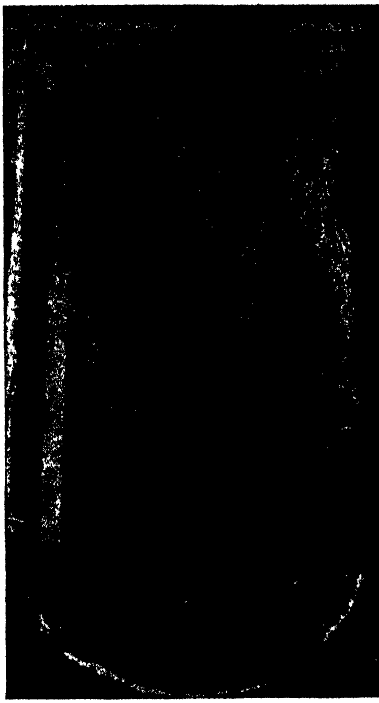

FIG. 3.—The root system of a mature plant of the Krug variety grown in a pot (16 x 36 inches.) Approximately one-half of the roots have been exposed by washing.

The number of root-bearing nodes, as well as the total number of nodes per stalk increased with varietal size (Table 1). The lowest 8, 12, and 14 stalk nodes of the small, medium, and large types, respectively, bore roots. Of these, the 7, 8, and 9 nodes occurring belowground and usually the first one aboveground in the respective types bore functional roots. The roots from higher nodes were non-functional and failed to reach the soil.

The various types were rather similar in regard to the percentage of stalk nodes with roots. These percentages were, respectively, 42, 48, and 48.

SPREAD OF SECONDARY ROOT SYSTEM

The spread of roots is expressed in two ways in this paper, *viz.*, (a) the *maximum spread* of any main root from the base of the plant, and

(b) the *average spread* of main roots arising from that node whose roots attain the greatest average distance from the stalk. In general, both the maximum and average spread tended to increase with varietal size. The maximum spread was 36, 48, and 54 inches (Table 2) for the small, medium, and large varieties, respectively, whereas the average spread for the respective types was 35, 39, and 38 inches. The corresponding relative values for maximum spread were 100, 133, and 150% compared with 100, 111, and 109% for the average spread.

TABLE 1.—*The comparative stalk development at maturity and the number of days from planting to tasseling and to ripening of the small, medium, and large corn types.*

Characters observed	Varietal type		
	Small	Medium	Large
Number of varieties averaged	2	3	2
Individual plant data:			
Days from planting to tasseling	50	65	79
Days from planting to ripening	88	112	129
Height to first tassel branch, in	55	87	92
Leaf area sq. in	658	1,412	1,747
Stalk diameter at base, mm	22	27	32
Moisture-free fodder weight, grams	248	380	622
Nodes:			
Total number	19	25	29
Bearing roots	8	12	14
Relative no. bearing roots, %	42	48	48
Above ground with leaves	12	17	20
Above ground with roots	1	4	5
Below ground with roots	7	8	9
With functional roots	8	9	10
With functional aerial roots	1	1	1
With non-functional aerial roots	0	3	4
Acre yield:			
Stover, lbs	1,766	3,628	4,458
Grain, bu	23	37	19

The spread of approximately one-fourth of all the roots of each regional type exceeded 1.5 feet, whereas it was less than this amount for the remaining three-fourths of the roots. This suggests that the widely spreading 25% of the roots of individual plants occupied 3 times as large a soil volume as the nearly vertical 75%. The widely spreading roots arose from the lowest three, four, and five nodes of the small, medium, and large varieties, respectively, while the nearly vertical roots grew from the next five higher nodes of each type. These principles are depicted in Fig. 4 which is a graphic presentation of the secondary root systems of the three types.

In general, the spread was greatest for the roots from the lower stalk nodes and decreased as nodal position on the stalk became higher. For the small, medium, and large types the mean spread of roots from the lowest stalk node (Tables 2 and 3) was, respectively, 35, 35, and 34 inches, but from the highest node with functional roots only 7, 6, and 5 inches.

TABLE 2.—*The comparative development of the secondary root system of the small, medium, and large corn types at maturity.**

Characters observed	Varietal type		
	Small	Medium	Large
Number of varieties averaged	2	3	2
Lateral spread of roots:			
Maximum, in.	36	48	54
Average for node† with greatest root spread, in.	35	39	38
Av. for lowest stalk node, in.	35	35	34
Av. for highest node with functional roots, in.	7	6	5
Depth of root penetration:			
Maximum, in.	67	73	74
Average, in.	47	54	58
Functional roots	60	85	99
Non-functional aerial roots	3	47	81
Combined length of main roots, ft.	283	346	545
Combined length‡ of main roots and branches, miles	5	6	9
Branches per inch of main root**	11	12	10
Root diameter, mm.**	1.5	1.7	2.1
Root volume, cc.††	403	749	1,484
Root weight, grams††	36	77	148
Dry weight‡ of roots per acre, lbs.	445	1,080	1,420

*All data are for plants grown in the field except volume and weight which were determined from plants grown in pots.
†This node was the 1st, 2nd, and 2nd in the small, medium, and large types, respectively.
‡Estimated.
**Average of the measurements near the base, midpoint, and tip of roots.
††One variety of each type was grown in triplicate pots.

DEPTH OF ROOT PENETRATION

The deepest penetrating roots at maturity were usually observed in the larger types. The maximum depth of penetration averaged 67, 73, and 74 inches (Table 2) for the small, medium, and large varieties, respectively, while the average depth of penetration for all main roots was 47, 54, and 58 inches for the corresponding varieties.

COMBINED LENGTH OF ROOTS

The combined length of all the main roots per plant at maturity (Table 2) was materially greater for the larger varieties. For the small, medium, and large types, respectively, these values were 283, 346, and 545 feet. It is estimated that the combined length of the branches was at least 90 times greater than that of the main roots. Accordingly, a plant of each of the respective types would possess about 5, 6, and 9 miles of roots (including branches).

NUMBER AND NODAL ORIGIN OF ROOTS

The larger varieties were found to have more functional and non-functional roots per plant. Functional roots arose from the underground nodes and usually the first node aboveground. The roots from higher nodes commonly desiccated before reaching the soil. The small, medium, and large types averaged 60, 85, and 99 functional roots per plant (Tables 2 and 3) which grew from the first 8, 9, and 10

nodes, respectively. Including the non-functional aerial roots from higher nodes the total number per plant for the respective types was 63, 132, and 180.

The larger varieties in contrast to the small had more root-bearing nodes per plant as well as a few nodes with higher numbers of roots. The 9th, 13th, and 17th were the uppermost nodes from which roots

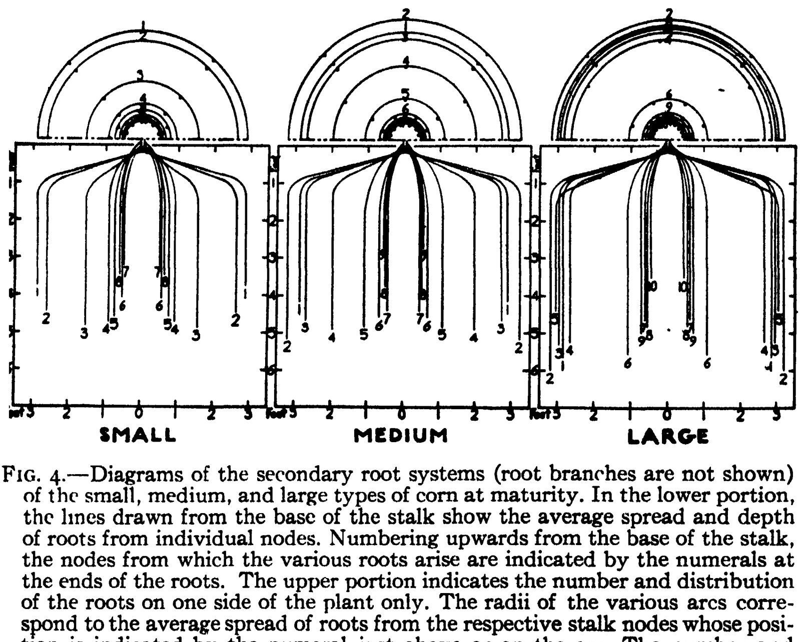

FIG. 4.—Diagrams of the secondary root systems (root branches are not shown) of the small, medium, and large types of corn at maturity. In the lower portion, the lines drawn from the base of the stalk show the average spread and depth of roots from individual nodes. Numbering upwards from the base of the stalk, the nodes from which the various roots arise are indicated by the numerals at the ends of the roots. The upper portion indicates the number and distribution of the roots on one side of the plant only. The radii of the various arcs correspond to the average spread of roots from the respective stalk nodes whose position is indicated by the numeral just above or on the arc. The number and approximate location of roots is shown for individual nodes by the small circles distributed systematically along the corresponding arcs.

were observed to grow in the small, medium, and large varieties, respectively (Table 3). The number of roots per node increased rather progressively upwards from the lowest node, the maximum of 14.3, 20.1, and 22.0 roots occurring on the 7th, 9th, and 10th nodes, respectively, of the three types.

NUMBER OF BRANCH ROOTS PER INCH OF MAIN ROOT

The data (Table 4) suggest that the largest varieties had a few less branches per inch of main root than either the small or the medium sorts. For all types, the number of branches near the base of the root was greatest for roots from higher stalk nodes. These numbers for roots from the two lowest and two highest stalk nodes were 15 and 26 per inch, respectively. The number of branches tended to decrease with distance from the base of the root. The averages for all nodes were 19 near the base, 9 near the midpoint, and 6 near the tip of the root.

TABLE 3.—*The average number and lateral spread of roots from successive stalk nodes of the small, medium, and large corn types at maturity.*

Stalk node	Mean lateral spread of roots from successive nodes, in.			Number of roots per node		
	Small	Medium	Large	Small	Medium	Large
1	34.5	34.5	34.2	4.4	4.2	4.5
2	31.3	38.7	38.3	4.2	4.1	4.6
3	18.6	32.3	35.6	4.0	4.4	4.7
4	10.8	23.7	32.0	5.2	5.6	5.8
5	7.4	12.0	36.0	7.3	7.1	6.6
6	6.4	8.0	13.1	11.0	9.3	8.4
7	6.0	5.7	7.3	14.3	13.1	11.6
8	6.8	6.0	6.9	11.2	16.8	15.8
9	—	6.4	8.5	1.6	20.1	19.0
10	—	—	5.4	—	19.6	22.0
11	—	—	—	—	16.8	21.9
12	—	—	—	—	7.9	19.8
13	—	—	—	—	2.6	17.2
14	—	—	—	—	—	9.8
15	—	—	—	—	—	5.2
16	—	—	—	—	—	2.3
17	—	—	—	—	—	0.5
Functional*	—	—	—	60.3	84.6	98.6
Non-functional	—	—	—	2.7	46.9	81.0
Total	—	—	—	63.0	131.5	179.6

*Functional main roots grew from the lowest 7.9, 8.0, and 9.8 stalk nodes of the small, medium, and large types, respectively. Roots from higher nodes commonly desiccated before reaching the soil.

DIAMETER OF MAIN ROOTS

The diameter of main roots of the medium and large types exceeded that for the corresponding nodes of the small type an average of 10 and 29%, respectively. The root diameter increased, progressively, from the lowest to the highest node. Near the base of the roots it averaged 1.2 mm for the two lowest nodes and 6.3 mm for the two highest nodes (Table 4). The diameter of the individual roots tended to decrease towards the tip. It averaged 1.2, 0.9, and 0.7 mm near the base, midpoint, and tip, respectively, of roots arising from the two lowest nodes, and 6.3, 1.2, and 0.8 mm for those originating in the two highest nodes.

VOLUME AND WEIGHT OF ROOTS

The aerial development at maturity of the small, medium, and large varieties grown in pots is compared in Table 5 with that of the corresponding regional types grown in the field. As it was rather similar for both types of culture, considerable credence is given to the root measurements.

The volume and weight of roots increased decidedly with varietal size. The root volume was 403, 749, and 1,484 cc (Table 5) for the small, medium, and large varieties, respectively, while the corresponding moisture-free weights were 36, 77, and 148 grams. The mois-

TABLE 4.—*The number of branches per inch of functional* main root and the diameter of functional main roots of the small, medium, and large corn types at maturity.*

Varietal type	Mean number of branches per inch of main root for nodes indicated			Mean diameter of main roots for nodes indicated, mm		
	2 lowest	2 highest	All nodes	2 lowest	2 highest	All nodes
			Near Base of Root			
Small.........	14.2	25.8	19.4	1.1	5.6	2.9
Medium......	17.2	27.4	21.0	1.3	6.0	3.5
Large.........	13.1	23.9	17.5	1.2	7.2	4.1
Average.....	14.8	25.7	19.3	1.2	6.3	3.5
			At Mid-point of Root			
Small.........	7.4	10.7	9.2	0.8	0.9	0.9
Medium......	10.3	12.6	10.6	0.9	1.3	1.1
Large.........	6.9	10.6	8.4	1.0	1.3	1.2
Average.....	8.2	11.3	9.4	0.9	1.2	1.1
			Near Tip of Root			
Small.........	5.7	6.3	5.9	0.7	0.7	0.7
Medium......	5.8	6.0	5.9	0.6	0.8	0.6
Large.........	4.2	5.2	4.8	0.8	0.9	0.9

*Refer to Table 3.

TABLE 5.—*The vegetative development of representative small (Rustler), medium (Krug), and large (Mexican June) corn varieties grown to maturity in pots.*

Type	Variety	In percentage of the respective types grown in the field			Root volume, cc	Moisture-free		Fodder weight ÷ root weight
		Plant height	Number of leaves	Moisture-free fodder		Root weight, grams	Fodder weight, grams	
Small...	Rustler	103	95	93	403	36	231	6.42
Medium	Krug	91	93	99	749	77	377	4.90
Large	Mexican June	120	100	83	1,484	148	514	3.47
Average........		105	96	92	—	—	—	—

ture-free fodder weights (including the base of the stalk) were 6.42, 4.90, and 3.47 times as heavy as the moisture-free root weights of the respective types. The acre yield of moisture-free fodder for plants spaced 21 inches in rows 42 inches apart was 2,870, 5,285, and 4,920 pounds for the small, medium, and large types, respectively. Dividing these yields by the corresponding fodder-root weight ratios, it may

be calculated that the respective types added approximately 445, 1,080, and 1,420 pounds of dry root material per acre to the soil during the 1933 growing season. The computation for the medium varieties is corroborated by King (3) who estimated the amount to be 1,130 pounds and by Miller (4) whose calculation was 1,125 pounds.

TABLE 6.—*Vegetative development of the small, medium, and large corn types at progressive intervals after the planting date.*

Regional type	Aboveground parts				Secondary root system			
	Plant height, in.*	Leaf area, sq. in.	No. of leaves	Moisture-free fodder, grams	Av. depth of root penetration, in.	No. nodes bearing roots	Main roots: Combined length, feet	Main roots: No. functional
	2 Weeks After Planting							
Small	9.8	—	5.8	—	5	2.0	6	5.0
Medium	10.0	—	6.2	—	4	1.7	4	5.3
Large	10.5	—	5.8	—	6	1.5	5	5.5
	4 Weeks After Planting							
Small	29.5	167	9.0	12	11.4	3.5	28	18.5
Medium	28.0	160	9.0	9	8.3	4.0	28	18.3
Large	26.5	161	8.5	9	12.6	4.0	31	19.5
	6 Weeks After Planting							
Small	47.4	566	11.5	66	25.4	6.0	70	42.5
Medium	54.4	888	13.7	70	26.6	7.3	92	47.0
Large	53.8	818	13.5	67	24.4	6.5	104	48.0
	8 Weeks After Planting							
Small	54.7	501	12.3	128	30.2	8.0	185	62.0
Medium	80.6	1,278	16.1	274	36.3	10.0	247	78.3
Large	80.2	1,590	16.5	238	34.5	11.0	301	89.0
	12 Weeks After Planting							
Small	54.7	658	11.9	248	47.4	8.0	283	55.5
Medium	86.7	1,412	16.9	382	49.0	10.0	364	84.3
Large	92.1	1,764	20.4	364	50.2	12.5	445	96.0
	Mature							
Small	54.7	658	11.9	248	47.4	7.9	283	60.3
Medium	86.7	1,412	16.9	380	54.4	11.6	346	84.6
Large	92.1	1,747	20.4	622	57.5	13.6	545	98.6

*For measurements inclusive of the 6th week in the small type and the 8th in the others, the leaves were held erect. Subsequent measurements were taken to the basal tassel branch.

DIFFERENCES BETWEEN TYPES AT IMMATURE STAGES

While greatest interest is attached to mature vegetative development, some noteworthy observations were made at earlier stages. Periodic measurements of a few aerial and root characters are reported for the three types in Table 6.

Vegetative development proceeded with about equal rapidity for all varieties until the small type came in tassel 7 weeks after planting.

Thereafter, development in the small type was surpassed by that of the medium and the large. Similarly, aerial and root development of the large type exceeded that of the medium as the latter approached its tasseling date 9 weeks after planting. Nearly the full stalk height, the entire area and number of leaves, all the nodes bearing roots, and the full number of functional roots were attained by all types at their respective tasseling dates; however, fodder weight, combined length of main roots, and depth of root penetration increased to maturity. Accordingly, vegetative size and lateness of maturity are correlated.

The average depth of root penetration increased 12 inches or more in all types after coming into full tassel. These depths were approximately 28, 38, and 46 inches, respectively, for the small, medium, and large varieties on their tasseling dates of 7, 9, and 11 weeks after planting, whereas they were 47, 54, and 58 inches at maturity, or the respective ages of 13, 16, and 19 weeks.

SUMMARY

The heritable characteristics of the secondary root systems of corn varieties differing materially in aboveground size when grown under comparable conditions were studied at Lincoln, Nebr. To facilitate comparisons, the varieties were grouped on the basis of size into small, medium, and large vegetative types. The mean values for certain plant measurements in the three respective types at maturity were as follows: (a) Heights of 55, 87, and 92 inches; (b) leaf areas of 658, 1,412, and 1,747 square inches; (c) moisture-free fodder weights of 248, 380, and 622 grams; (d) 88, 112, and 129 days from planting to ripening; and (e) 8, 9, and 10 stalk nodes bearing functional main roots.

The size of the secondary root system tended to increase with that of the aboveground parts. Based on the small type, the medium and large types had, respectively, (a) 33 and 50% greater maximum spread, while the average spread of main roots from that node whose roots attain the greatest average distance from the stalk was only 11 and 9% larger; (b) 9 and 10% deeper maximum penetration and 15 and 23% greater average depth of root penetration; (c) 42 and 65% more functional main roots; (d) 22 and 92% greater combined length of main roots per plant; (e) 115 and 311% greater root weight; (f) 86 and 268% greater root volume; and (g) 10 and 29% larger diameter of main roots.

Roots spreading less than 1.5 feet from the stalk were approximately 3 times as numerous in all types as those spreading more than this distance. These wide-spreading roots grew from the lowest 3, 4, and 5 nodes of the small, medium, and large varieties, respectively.

The moisture-free weight of tops in the small, medium, and large varieties, respectively, was 6.42, 4.90, and 3.47 times as great as that of the roots. From these figures, it was estimated that 445, 1,080, and 1,420 pounds of dry root material per acre were left in the soil by the current crop of the respective types.

The rapidity of root as well as top growth was approximately the same for all types until the occurrence of tasseling in the small varieties. Thereafter, more vigorous growth caused the medium and large types to surpass in these respects. Similarly, as the medium type commenced tasseling, its vegetative development was exceeded by that of the large. The outcome of this behavior is a rather high correlation between root and top growth.

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THE COMPARATIVE ROOT DEVELOPMENT OF SELFED LINES OF CORN AND THEIR F_1 AND F_2 HYBRIDS[1]

T. A. KIESSELBACH AND RALPH M. WEIHING[2]

THE hybrid vigor of first generation crosses between unrelated self-fertilized lines of corn and its reduction in the second generation is readily apparent and well known with respect to the aerial parts of the plant. The corresponding responses of the root system are more obscure and less understood. It has been the purpose of these investigations to study the extent to which heterosis may be exhibited by the root development of this crop.

DESCRIPTION OF SEED STOCKS

Two standard, homozygous lines of dent corn, Indiana B-2 and Iowa 197, and their F_1 and F_2 hybrids were studied in 1933 and a corresponding group, Illinois A and Iowa 420, and their F_1 and F_2 hybrids in 1934. These four lines are well adapted for use in hybrids suitable for eastern Nebraska conditions.

METHODS OF TESTING

Since it was the desire to limit the observations to heritable differences, the various lots were grown comparably each year with the plants spaced individually 7 feet apart in adjacent four-row plats. The tests were located on Carrington silt loam soil at Lincoln, Nebr. The plats were sweep cultivated at sufficient depth merely to destroy weeds without disturbing the main roots of the corn. The climatic conditions were conducive to normal growth in 1933. The rainfall was deficient in 1934 and supplementary irrigation was uniformly applied as needed. The root inspections were made at maturity by the use of technic recently described by Weihing.[3] Detailed observations were limited to the secondary root system since it comprises the bulk of the roots. Because of the large amount of labor involved the root examinations were confined to four plants of each selfed line and hybrid.

VEGETATIVE DIFFERENCES AT MATURITY

The customary aerial differences between selfed lines and their first and second generation hybrids are reflected in Table 1. Although the annual results for both stalks and roots are reported, the averages for the 2 years doubtless serve better to indicate mean expectations. The stalk and root development of representative plants grown in 1934 are shown in a single plane in Fig. 1.

Stalk development.—The F_1 hybrids show a material increase in the size of aboveground parts over the inbred parents, while the F_2 generation tends to be intermediate. Comparing the selfed lines, the F_1 hybrids, and the F_2 hybrids with respect to certain characters, their relative stalk heights were 100, 128, and 114; their relative

[1]Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station. Lincoln, Nebr. Paper No. 166, Journal Series, published with the approval of the Director. Received for publication April 4, 1935.

[2]Agronomist and Assistant Agronomist, respectively.

[3]WEIHING, RALPH M. The comparative root development of regional types of corn. Jour. Amer. Soc. Agron., 27 : 526–537. 1935.

TABLE 1.—*The comparative development of the stalk and the secondary root system of selfed lines* of corn and their first and second generation hybrids, 1933 and 1934.*

Inbred parents and their hybrid generations	Stalk				Main roots						
	Plant height, in.	Leaf area per plant, sq. in.	Fodder weight (moist.-free), grams	No. nodes with functional roots	Depth of penetration, ft.		Maximum spread†, ft.	Combined length, ft.	Number	Mean‡ diameter, mm	No. root-branches per inch
					Av. all roots	Maximum					
					1933						
Ind. B-2	67	806	272	9	3.0	4.2	3.6	295	60	1.8	14.1
Iowa 197	71	878	245	9	3.4	4.5	3.0	255	68	1.7	15.8
F_1	88	1077	433	9	4.3	5.8	3.7	361	76	2.2	13.3
F_2	74	945	347	9	3.8	5.1	3.7	341	74	2.0	13.4
					1934						
Ill. A	72	561	86	11	3.1	4.2	2.1	409	107	1.2	13.1
Iowa 420	79	759	181	9	3.1	4.1	3.7	354	80	1.3	11.2
F_1	96	1066	411	10	4.9	7.2	3.4	590	96	1.6	11.7
F_2	90	795	298	9	4.0	5.8	2.5	450	94	1.4	12.2
					Average for 2 Years						
Inbreds	72	751	196	9.5	3.2	4.2	3.1	328	79	1.5	13.6
F_1	92	1072	422	9.5	4.6	6.5	3.6	476	86	1.9	12.5
F_2	82	870	322	9.0	3.9	5.4	3.1	396	84	1.7	12.8

*The selfed lines have been continued by inbreeding in Nebraska for a number of generations from seed originally secured from J. R. Holbert and M. T. Jenkins of the U. S. Dept. of Agriculture.

†Root spread represents the distance from base of the stalk to the farthest lateral point.

‡Average of measurements near the base, midpoint, and tip of all main roots.

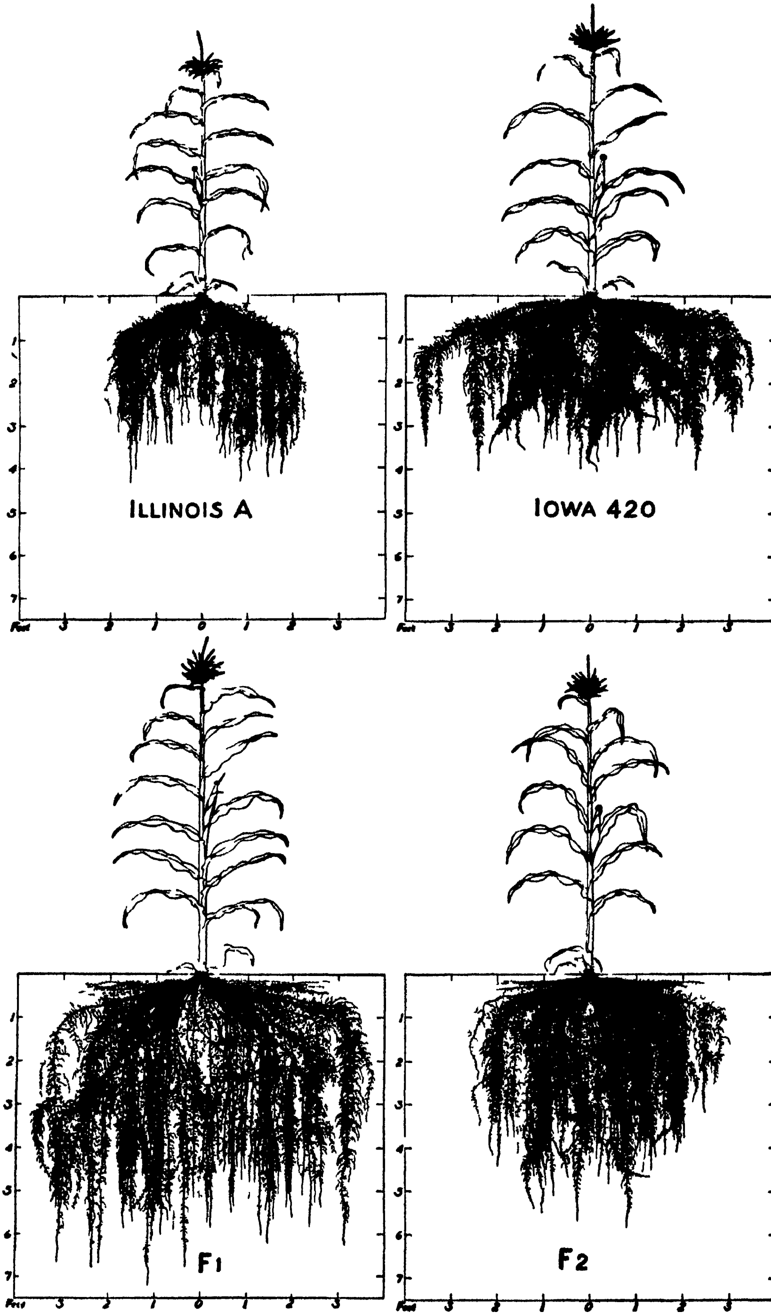

FIG. 1.—Representative plants of the selfed lines Illinois A and Iowa 420 and the F_1 and F_2 hybrids between them. Approximately 25% of the branch roots are shown.

leaf areas per plant 100, 143, and 116; and their relative moisture-free fodder weights 100, 215, and 164.

Root development.—Upon hybridization, the depth of penetration, the combined length of all main roots per plant, and the diameter of main roots (Table 1) increased materially in the first generation, while in the second generation they were intermediate. Thus, comparing the selfed lines and the first and second generation hybrids, the relative maximum root penetrations were, respectively, 100, 155, and 129; the relative mean penetrations of all roots per plant 100, 144, and 122; the relative combined lengths of all the main roots per plant 100, 145, and 121; and the relative mean root diameters 100, 127, and 113. The corresponding relative maximum root spread of the three types was, respectively, 100, 116, and 100. Upon hybridization the number of branches per unit length of main roots decreased 8 and 6%, respectively, in the first and second generations. This may undoubtedly be accounted for by the tendency of individual cells of hybrids to grow larger as found by Kiesselbach,[4] causing a wider separation of the branch roots.

It is evident that inbred lines may differ materially in some root characters as number of main roots per plant, number of branches per unit length of main root, and lateral root spread. In general, the root development in subsequent hybrid generations exhibits heterosis, as does stalk development.

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[4]KIESSELBACH, T. A. Corn investigations. Nebr. Agr. Exp. Sta. Res. Bul. 20. 1922.

RELATIVE PROMPTNESS OF NODULE FORMATION AMONG VETCHES, VETCHLINGS, WINTER PEAS, CLOVERS, MELILOTS, AND MEDICS[1]

J. F. DUGGAR[2]

THE conditions under which root nodules develop most readily on the roots of leguminous plants have been less intensively studied than the importance of the subject warrants. The more elaborate of the investigations have been conducted in the laboratory, where the host legumes necessarily have been subjected to highly artificial conditions. These and other considerations pointed to the need for supplementary investigations to supply data on the development of root nodules under field conditions, hence a series of field experiments has been conducted for a number of years on the Experiment Station farm at Auburn, Ala.[3]

This paper is a report on one of a series of field studies to determine to what extent, if at all, winter legumes differ among themselves in their promptness or tardiness in developing root tubercles when planted in the field at usual or typical dates in the fall.

METHODS

Two plantings of all species were made each year, the first as near to October 1 and the second to November 1, as practicable. The seed were planted in rows 3 feet apart at a depth of 2 inches for the vetch group and of 1 inch for the small-seeded group. This field, of Norfolk sandy loam, was annually prepared, fertilized, and cropped as uniformly as possible. Phosphate in moderate amount was applied early each year and out of contact with the seed. Samples consisting of as many plants as practicable were collected at intervals of one to several days from three or more locations on each plat and the nodules were counted.

Generalized nodulation was considered as occurring when 85% or more of the plants of a given sample were found to bear one nodule or more. The day when a considerable percentage of the young seedlings came up and were thus first exposed to light was taken as the day of emergence. The term "nodulation period" is here used to designate the interval between emergence and generalized nodulation as defined above.

Seed of all species and for every date of planting were artificially inoculated by soaking them for about an hour in a suspension of the appropriate inoculum. Humus cultures from the same manufacturer were used each year on seed of all species. The micro-organisms appropriate to the vetches were widely distributed in this soil throughout the experimental period; but the bacteria suited to the clovers, melilots, and medics were absent or very scarce.

RESULTS

VETCHES, VETCHLINGS, AND WINTER PEAS

The average number of days between emergence and generalized nodulation of each species is shown in Table 1.

[1]Contribution from the Department of Special Investigations, Alabama Agricultural Experiment Station, Auburn, Ala. Received for publication April 8, 1935.

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[3]DUGGAR, J. F. Preliminary notes on time of nodulation of winter legumes. Ala. Agr. Exp. Sta., Ann. Rpts., 1926:22; 1927:26; and 1929: 25–26.

TABLE 1.—*Number of days between emergence and generalized nodulation for early October and early November plantings of vetches, vetchlings, and winter peas, 1926–1931.*

Kind of legume	Number of days in nodulation period from plantings made in		
	Early Oct.	Early Nov.	Av. of Oct. and Nov.
Wooly-pod vetch (*V. dasycarpa*)	6	7	6.5
Hungarian vetch (*V. pannonica*)	7	7	7.0
Hairy vetch (*V. villosa*)	7	8	7.5
Monantha vetch (*V. monantha*)	6	9	7.5
Oregon vetch (*V. sativa*)	6	10	8.0
Narrow-leaved vetch, northern (*V. angustifolia*)	8	9	8.5
Austrian pea (*Pisum sativum*)	7	10	8.5
Narrow-leaved vetch, southern (*V. angustifolia*)	9	9	9.0
Tangier pea (*Lathyrus tingitanus*)	7	12	9.5
Purple vetch (*V. atropurpurea*)	8	12	10.0
Pearl vetch (*V. sativa*)	11	11	11.0
Bitter vetch (*V. ervilia*)	10	16	13.0
Lentil (*Ervum lens*)	12	14	13.0
Scotch vetch (*V. sativa*)	14	13	13.5
Sweet pea (*L. odoratus*)	17	22	19.5
Horse bean, small seeded (*V. faba*)	19	25	22.0
Grass pea, late white (*Lathyrus sativus*)	14	32	23.0
Grass pea, early white (*L. sativus*)	12	37	23.5

The various cultivated species of vetches, vetchlings (*Lathyrus* sp.), and Austrian winter pea differed materially in their promptness in forming root nodules. Woolly-pod, Hungarian, hairy, monantha, Oregon, and narrow-leaved vetches, and Austrian pea were almost always very prompt in attaining generalized nodulation. The average time that they required between emergence and generalized nodulation was 6½ to 8½ days. Tangier pea, purple vetch, and Pearl vetch followed closely with nodulation periods that averaged 9½ to 11 days under these conditions. Bitter vetch and Scotch vetch, with average nodulation periods of 13 and 13½ days, were distinctly later in nodulation than other vetches. Sweet pea, horse bean, and grass pea, with average nodulation periods of 19½, 22, and 23½ days, respectively, were slowest in reaching generalized nodulation. Species was obviously one of the factors determining the promptness or tardiness of nodule formation.

The most surprising contrast in the time required for generalized nodulation was afforded by a comparison of Oregon and Scotch vetches. To become moderately stocked with root nodules, Oregon vetch required on an average only 8 days against 13.5 days for Scotch vetch. These are in the same species (*V. sativa*) and the young plants are indistinguishable. Their chief agronomic differences were found here to consist of much greater earliness for the Scotch vetch and a far greater susceptibility of this strain to injury from low winter temperatures. Apparently variety, as well as species and genera, may affect nodulation.

CLOVER, MEDICS, AND MELILOTS

The average number of days from emergence to generalized nodulation of each species of numerous clovers, medics, and melilots is shown in Table 2.

TABLE 2.—*Number of days between emergence and generalized nodulation for October and November plantings of clovers, meliots, and medics, 1926–1931.*

Kind of legume	Average number of days in nodulation period from plantings made in		
	Early Oct.	Early Nov.	Av. of Oct. and Nov.
Crimson clover (*T. incarnatum*)	31	23	27
Red clover (*T. pratense*)	28	41	34
Alsike clover (*T. hybridum*)	22	21	21
White Dutch clover (*T. repens*)	33	16	24
Ladino clover (*T. repens latum*)	23	23	23
Subterranean clover (*T. subterraneum*)	20	20	20
White biennial melilotus (*Melilotus alba*)	29	21	25
Yellow annual melilotus (*M. indica*)	29	46	37
Early bur clover, spotted leaf (*Medicago arabica*)	11	35	23
California bur clover (*M. hispida*)	28	49	38
Alfalfa, average of common, Grimm, and Hairy Peruvian (*M. sativa*)	26	43	34

The clovers, melilots, and medics presented no marked and constant difference in rate of nodulation that might be attributed to diversity in genera. There were greater differences among individual species within the same genera than between any two genera. Specific difference between *Medicago arabica* and *M. hispida* may be noted.

DISCUSSION

Every species of clover, melilot, and medic tested required a much longer average time to attain a stage of generalized nodulation than did representative species in the vetch group. This difference may be due to any one or more of the following factors: Specific visible dissimilarities in the two classes of host plants, inherent unidentified differences among the hosts, and variations in environment. The plants of the vetch group made more extensive early growth of both tops and roots, due in part to larger reserves contained in the seeds. Their environment was also somewhat more favorable in one respect. They were free to utilize not alone the appropriate inoculum, which was supplied to all seeds of both classes, but the vetches were able also to make use of the vetch bacteria that were abundant in this soil as the result of the earlier growth of narrow-leaved vetch. No corresponding supply was available in this acid soil (pH 4.7 to 5.3) of micro-organisms suitable to the clovers, melilots, and medics. It seems probable that any adverse condition, such as too great acidity or dryness, would more effectively reduce or delay nodule formation that results merely from inoculation of seed than it would be able to restrict nodule development due to bacteria carried by both seed and soil.

Specific differences were shown in the readiness with which different species within the same genus became stocked with root nodules. For example, bitter vetch (*V. ervilia*) required 13 days for generalized nodulation against 6.5 to 8 days for most other species of *Vicia*. Moreover, California bur clover (*Medicago hispida*) required 38 days for generalized nodulation against 23 days for spotted-leaf bur clover (*M. Arabica*).

SUMMARY

Artificially inoculated seed of numerous species of vetches, vetchlings, winter peas, clovers, melilots, and medics were planted twice each fall through a 6-year period. Frequent counts of root nodules were made.

Average figures are presented which show for each species the length of time between the emergence of each lot of seedings and generalized nodulation.

The vetches showed significant differences among species in the length of time required to attain a condition of generalized nodulation.

Leading in promptness of nodule formation were woolly-pod, Hungarian, hairy, Monantha, Oregon, and narrow-leaved vetches, and Austrian pea, with averages of only 6½ to 8½ days from emergence to the stage of generalized nodulation.

These were rather closely followed by Tangier pea, purple vetch, and Pearl vetch, which required an average of 9½ to 11 days.

Slowest of the "vetch group" species were sweet pea, horse bean, and grass pea, with average initial nodulation periods of 19½ to 23½ days.

The nodulation periods of bitter vetch and lentil were of intermediate length, with averages of 13 days each.

Scotch vetch, a very early strain, had an average nodulation period of 13½ days, or nearly 70% longer than that of Oregon vetch. These are both strains of *Vicia sativa*.

The interval between emergence and generalized nodulation was longer for the clovers, melilots, and medics than for typical vetches. This dissimilarity is attributed partly to specific characteristics of the host legumes and partly to difference in the kinds of bacteria in the soil.

A NEW LEGUME IN MONTANA[1]

J. R. GREEN AND H. E. MORRIS[2]

A NEW legume (*Astragalus* sp.) was found growing on some farms in the Ruby Valley in the vicinities of Waterloo and Twin Bridges, Mont. Records indicate that it attracted attention on the farm of John Masolo near Waterloo about 6 years ago. It thrived in a high-lime soil on moist bottomland containing more or less alkali (Table 1), where the water table was 3 feet or less from the surface.

TABLE 1.—*Alkali salts in soil on which new legume is growing.**

Depth of sample	Sulfates as Na_2SO_4 %	Sulfates as Na_2SO_4 Pounds per acre foot	Carbonates as Na_2CO_3 %	Carbonates as Na_2CO_3 Pounds per acre foot	Chlorides as NaCl %	Chlorides as NaCl Pounds per acre foot	Total
			Sample No. 1				
1st foot....	0.393	13,755	0.019	665	0.048	1,680	
2nd foot...	0.077	2,695	0.013	455	0.010	350	
3rd foot...	0.057	1,995	0.011	385	0.008	280	
4th foot...	0.055	1.925	0.013	455	0.006	210	
Total...	—	20,370	—	1,960	—	2,520	24,850
			Sample No. 2				
1st foot ..	0.190	6,650	0.016	560	0.016	560	
2nd foot...	0.104	3,640	0.011	385	0.008	280	
3rd foot. .	0.042	1,470	0.011	385	0.005	175	
4th foot...	0.042	1,470	0.011	385	0.003	105	
Total...	—	13,230	—	1,715	—	1,120	16,065
			Sample No. 3				
1st foot....	1.211	42,385	0.027	945	0.157	5,495	
2nd foot...	0.225	7,875	0.011	385	0.035	1,225	
3rd foot...	0.067	2,345	0.011	385	0.008	280	
4th foot...	0.060	2,100	0.011	385	0.006	210	

*Sulfates, carbonates, and chlorides determined as the ions and calculated as percentage and total sodium salts in one acre foot, 3,500,000 pounds being taken as the weight to one acre foot.

About a year ago this plant was called to the attention of the writers by John Ruppel of Twin Bridges because it was producing a considerable amount of palatable forage of apparently good quality.

This wild pea makes an abundant growth from the crown of a woody root (Fig. 1). It spreads out over the ground for 2 to 3 feet as a dense mat and soon crowds out other vegetation, forming relatively pure stands. The slender stems of the plant may grow to 4 feet

[1]Contribution from Montana, Agricultural Experiment Station, Bozeman, Mont. Paper No. 49, Journal Series. Received for publication April 8, 1935.

[2]Chemist and Botanist, respectively.

in length and bear many leaves 3 to 5 inches long (Fig. 2) Each leaf has about six pairs of leaflets and a terminal leaflet. Each leaflet is about 1 inch long and ½ inch wide. It is a very prolific producer of seed, each being about the size of an alfalfa seed

The roots are similar to those of alfalfa and bear many nodules The flowers are small, less than ¼ inch long, purplish in color, and like a pea flower The pods are small, numerous, about ¾ inch long, and usually contain about 10 seeds The growth is indeterminate; therefore there are mature pods, immature pods, and flowers occurring on the same stem.

On several ranches in the Ruby Valley this wild pea has been cut, cured, and stacked like alfalfa The yield of hay from this plant has not been determined, but there is no doubt that it has materially increased the production of forage on the ranches where it occurs It will probably never rival alfalfa in hay production as it produces only one hay crop a year, however, it does thrive on land that is not suitable for alfalfa, and all reports indicate that the hay is of high quality and that all kinds of stock seem to relish it

Feed analyses made by the authors (Table 2) show that it is like alfalfa as regards its content of protein, nitrogen-free extract, crude fiber, ether extract, and ash Another characteristic of this plant is that it contains a high percentage of phosphorus, considerably higher than alfalfa growing in the same region. This is very important because the soil generally in this particular section is deficient in phosphorus and livestock often show the effect of phosphorus-deficiency when fed only native

FIG 1 —*Astragalus rubyi* sp nov found in Montana. X 1/11.

grass. This plant, however, accumulates a large supply of phosphorus from this soil.

TABLE 2.—*Feed analyses of new legume.*

Description of sample	Protein %	Ash %	Ether extract %	Crude fiber %	Nitrogen-free extract %	P_2O_5 %
No. 1, composite of large plants of new legume from Farm B*..............	14.12	10.5	2.2	27.47	45.71	0.389
No. 2, composite of large plants of new legume from Farm M*..........	14.56	14.2	2.2	23.57	45.47	0.345
Av. 9 samples of alfalfa growing in same locality as the new legume.......	—	—	—	—	—	0.244
Av. Montana alfalfa.......	16.48	8.73	1.53	33.39	39.87	0.500
Av. Montana sweet clover..	15.73	7.64	1.66	31.93	43.50	—

*The samples of the new legume were cut at an advanced stage and thus the protein content is lower than if the plants had been cut earlier in the season. From the standpoint of the feed analyses it is very high in carbohydrates or nitrogen-free extract. Also, the phosphorus content (P_2O_5) is high for a feed growing on this particular soil.

Cultural experiments in comparison with alfalfa and other important forages must be conducted to determine the range of its

FIG. 2.—Young plant of *Astragalus rubyi* sp. nov. as found in Montana. X 3/10.

adaptability in regard to climate and soil. In addition, feeding experiments are needed to verify the reports of farmers regarding palatability and nutritive value. The results of such studies may show that this plant can have an important economic place in reclaiming low, damp bottom-land in the higher mountain valleys in Montana

and elsewhere. It may be used either as a forage or as a soiling crop. Attempts to identify this plant have been unsuccessful, therefore a description of the plant has been submitted for publication elsewhere under the name *Astragalus rubyi* sp. nov. Further studies of this plant are being made.

LIGHT INTENSITY AS AN INHIBITING FACTOR IN THE FIXATION OF ATMOSPHERIC NITROGEN BY MANCHU SOYBEANS[1]

Fred S. Orcutt and E. B. Fred[2]

RECENT biochemical studies indicate that the symbiotic association of rhizobia and leguminous plants is intimately related to the carbon-nitrogen balance in the plants. The results from many types of experiments (3)[3] indicate that an increase in carbohydrate synthesis favors fixation of nitrogen. A discussion of the literature on this subject is given by Wilson (7).

In most of the previous work emphasis is laid upon the stimulating effect of carbohydrate synthesis on nitrogen fixation; and the conclusion may be reached that any factor, e. g., light intensity or day length, that will increase the carbohydrate level in the plant will likewise *increase* nodule formation and nitrogen fixation. Conversely, any method which decreases the carbohydrate concentration, such as short exposure to light and addition of combined nitrogen to the substrate, will also *lower* nodule production and total nitrogen fixed.

In view of the evidence that nodule formation and nitrogen fixation are related to the photosynthetic activity of the plant, and since photosynthesis within limits is apparently proportional to light conditions, it appears reasonable to assume that light conditions and nitrogen fixation should have a positive correlation. The experiments reported in this paper were designed to measure the relation between light conditions and nitrogen fixation.

METHODS

Plant culture.—The plants were grown in glazed jars containing 11 kilos each of dry, sterilized, leached pit sand which contained no hot water extractable nitrogenous material. The soybean seed, of the Manchu variety, was sterilized by the method of Hopkins, Wilson, and Fred (4), planted in the bacterial-free sand to which had been added distilled water, and an aqueous suspension of a tested strain of *Rhizobium japonicum* added to jars to be inoculated. Enough seeds were planted so that 7 to 10 healthy plants could be obtained after thinning. The plants were watered with distilled water, and nitrogen-free Crone's solution (1) was added once a week.

Analytical—All plants were harvested early in the morning, from 7:00 to 9:00 o'clock. Leaves and stems were clipped and placed in a drying room at 60° C, roots were washed out of the sand with a stream of water, immersed in brine several minutes to loosen sand particles, and rinsed. Nodules were removed and both were dried at 60° C.

Total nitrogen was determined on an aliquot of the ground plant material by the official A. O. A. C. method. Samples in the first experiment were dried at 80° C for carbohydrate determinations. Total sugars were found by the Stiles,

[1]Contribution from the Departments of Agricultural Bacteriology and Agricultural Chemistry, University of Wisconsin, Madison, Wis. Herman Frasch Foundation in Agricultural Chemistry, Paper No. 95. Received for publication April 15, 1935.

[2]Research Assistant and Professor of Agricultural Bacteriology, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 558.

Peterson, and Fred (5) modification of the Shaffer-Hartman micro method. Light intensities were measured by the Weston Illumination Meter, Model 603.

EXPERIMENTAL

EXPERIMENT I. JUNE 1 TO JULY 13, 1932

Forty 2-gallon jars containing seven plants each were set up outside in a cold frame. The plants were divided into two groups for the following treatments: (a) Inoculated with nodule bacteria, and (b) given ammonium nitrate but no nodule bacteria. The nitrate was added at the rate of 25 mgm. of nitrogen three times a week, since this amount was sufficient to support the needs of the plants in each jar. During the growing period the days were unusually hot and the sun intensity approached a maximum. Although the soybeans had an abundance of nodules, they failed to initiate fixation of nitrogen. The nodules were large, well formed, and situated near the crown—the position usually associated with optimum fixation of nitrogen.

The gross appearance of the plants was yellow and pale green, stunted, stalky and dry, while uninoculated plants receiving ammonium nitrate under the same light conditions were growing tall, good green color, and succulent. At 5 weeks it was noticed that a few inoculated plants which were shaded from the direct rays of the sun during a short portion of the day were somewhat greener and more thrifty; evidently high light intensity was inhibiting either fixation or assimilation in the inoculated plants. To test this hypothesis a shield of heavily white-washed glass was erected to cut off the direct sun rays from one-half of each series of plants—inoculated and those receiving ammonium nitrate. There was at all times, however, an abundance of sky and reflected light. Two to 3 days after this change a very marked effect was noticeable in color, height, and succulence. After exactly *1 week* of shading, the plants were harvested (6 weeks from sprouting) and four representative jars were photographed from the inoculated series—two shaded and two unshaded (Fig. 1). The difference in height, color intensity, and leaf area is apparent. The root system of the shaded plants had nearly doubled in a week's time. The nodular development in both shaded and unshaded plants appeared to be equally good.

EXPERIMENT II

In the summer of 1933 a study was made of nitrogen fixation in soybeans under different light conditions, *viz.*, reduced intensity and short days as compared with full intensity and long day exposure. Plants were grown outside in a cold frame, all inoculated and then divided into the following treatments:

Group	Age	Treatment	Number of plants	Date of harvest
1	4 weeks	Unshaded	51	July 2
2	5 weeks	Unshaded	100	July 10
3	5 weeks	Shaded 1 week before harvest	50	July 10
4	5 weeks	Shaded 2 weeks before harvest	50	July 10
5	5 weeks	Short day	30	July 10

The controls harvested at 4 weeks, group 1, represent the condition of group 3 when shading was started. Group 4 had already been shaded 1 week by this time.

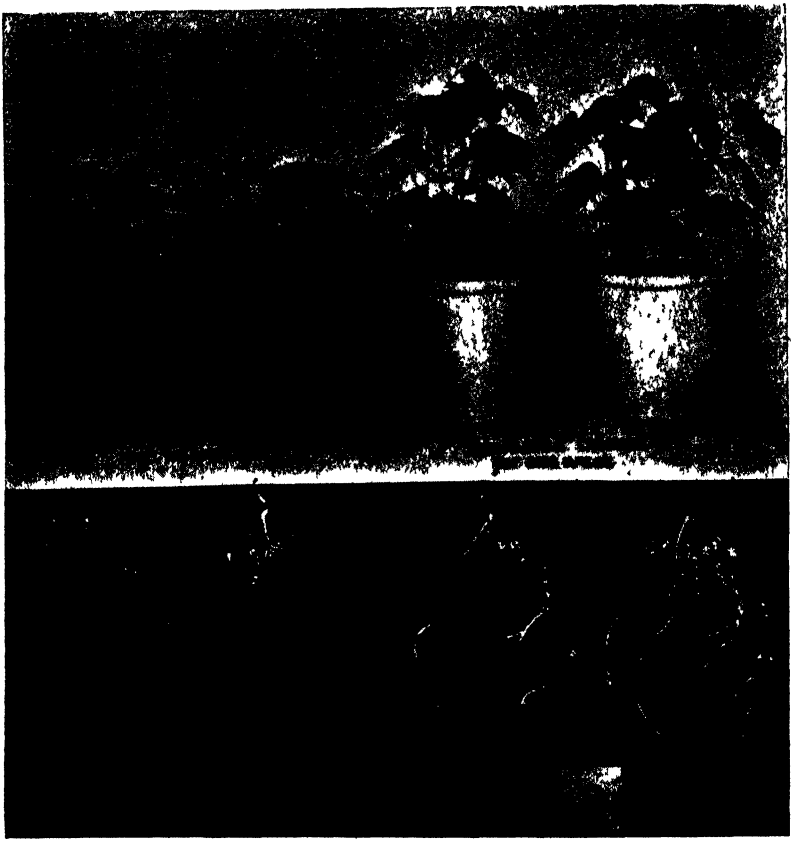

FIG. 1.—Effect of shading for 1 week on inoculated soybean plants grown in nitrogen-free sand.

Shading from the direct sun rays was accomplished with white-washed glass as in Experiment I. The light intensity under shaded conditions averaged 2,000 foot candles, and under normal conditions averaged better than 8,000 foot candles (measurements were made between 10 a.m. and 2 p.m.).

The temperature of the sand in groups 1 and 2 *just below the surface* reached a maximum of approximately 37°C shortly after mid-day. The corresponding temperature for shaded pots was approximately 35° C. The temperature decreased with the distance from the surface of the sand. The short day plants were given light from 9:00 in the morning until 4:30 in the afternoon. After this time the temperature

just below the surface of the pots in the dark chamber was approximately 5° C less than in those exposed to the sun.

EXPERIMENT III

This was much the same as the previous experiment. The plants were grouped as follows:

Group	Age	Treatment	Number of plants: *Rh. japonicum* strain 504	Number of plants: *Rh. japonicum* strain 10	Date of harvest
1	5 weeks	Unshaded	68	53	Aug. 7
2	5½ weeks	Unshaded	68	67	Aug. 11
3	5½ weeks	Shaded 4 days before harvest	67	54	Aug. 11
4	6 weeks	Unshaded	41	54	Aug. 14
5	6 weeks	Shaded 1 week before harvest	48	51	Aug. 14
6	6 weeks	Shaded 2 weeks before harvest	39	66	Aug. 14
7	6 weeks	Short day	41	41	Aug. 14

The controls, unshaded plants, harvested at five weeks represent the condition of 4- and 7-day shaded plants at the start of shading. The 14-day shaded plants had already been shaded 7 days by this time.

The light intensity under shaded conditions averaged 2,000 foot candles and under normal conditions 6,000 to 7,500 foot candles. The short day plants were darkened to an intensity of less than 4 foot candles when not exposed to full sunlight. Temperature observations were much the same as in Experiment II.

SUMMARY OF RESULTS

The absolute values for total nitrogen and dry weight per plant, as well as the soluble sugar levels, are given in Fig. 2 for the first experiment. It is apparent from the various staffs for total nitrogen per plant that the inoculated plants benefited by shading, whereas the reverse was true in uninoculated plants receiving nitrate. In the inoculated series, the nitrogen fixed per plant was 21.7 mgm. more in plants shaded 1 week than in those that were unshaded. The amount of nitrogen fixed in shaded plants was 116% greater than in those under higher light intensity. The same relationship as was found for total nitrogen was also true for dry weight. In inoculated plants there was a greater dry weight with shading, i. e., 590 mgm. per plant, or an increase of 43%. In contrast to this, the plants receiving nitrate were lower in dry weight with shading than the controls, i. e., 638 mgm. per plant, or 24% lower. This is the normal and expected response to decreased light intensity.

The concentration of sugars would be expected to decrease with decreasing intensity, but the staffs for sugar percentage show a much greater drop with shading in inoculated plants than in those receiving nitrate. This is correlated with the greatly increased fixation of nitro-

gen with shading. The appearance alone of these inoculated plants was sufficient to conclude that high intensity inhibited fixation, while reduced intensity for the short period before harvest accelerated the fixation process (Fig. 1).

The differences in Experiment II were similar to those of Experiment I, although not as striking. The data for total nitrogen and dry

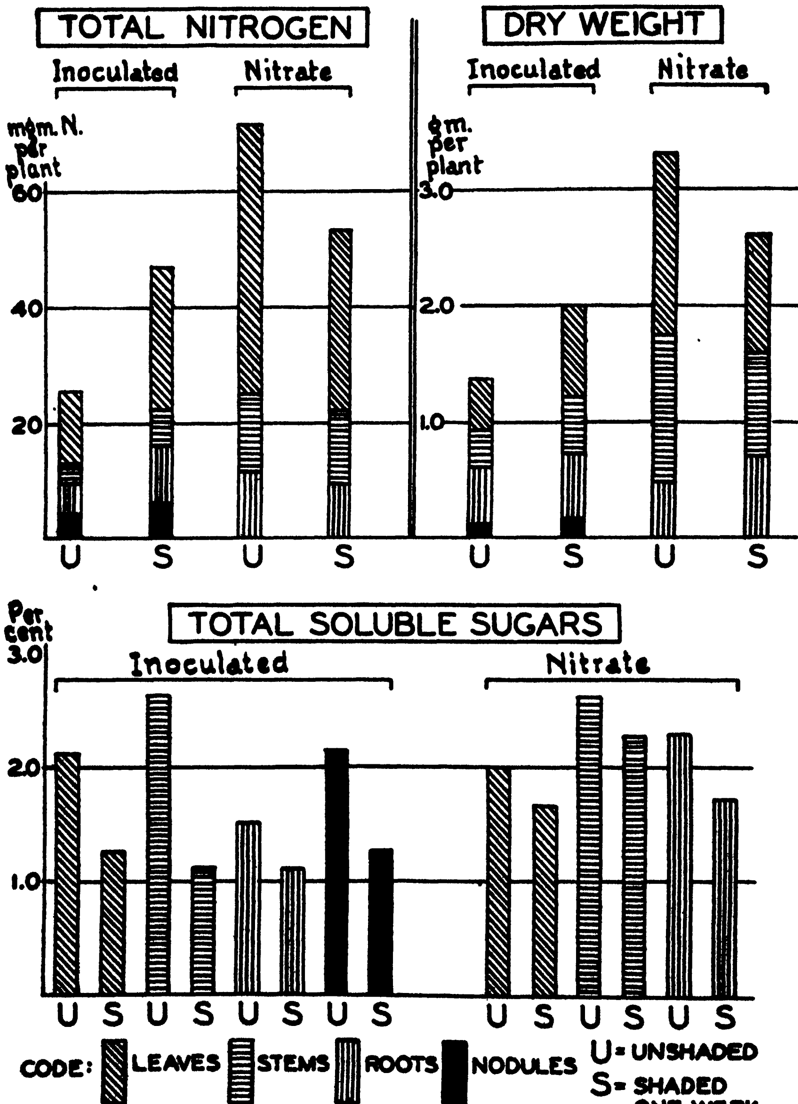

FIG. 2.—Effect of shading for 1 week on the total nitrogen, dry weight, and carbohydrate level of soybeans—inoculated plants vs. those receiving nitrate.

weight are plotted in the upper half of Fig. 3. The four staffs under "5 weeks" represent the various treatments. Plants shaded 1 week showed 25%, or 9.2 mgm., more nitrogen fixed per plant and 15%, or 270 mgm., more dry weight per plant than the unshaded controls at higher light intensity. The staff at the left of each major section, i. e.,

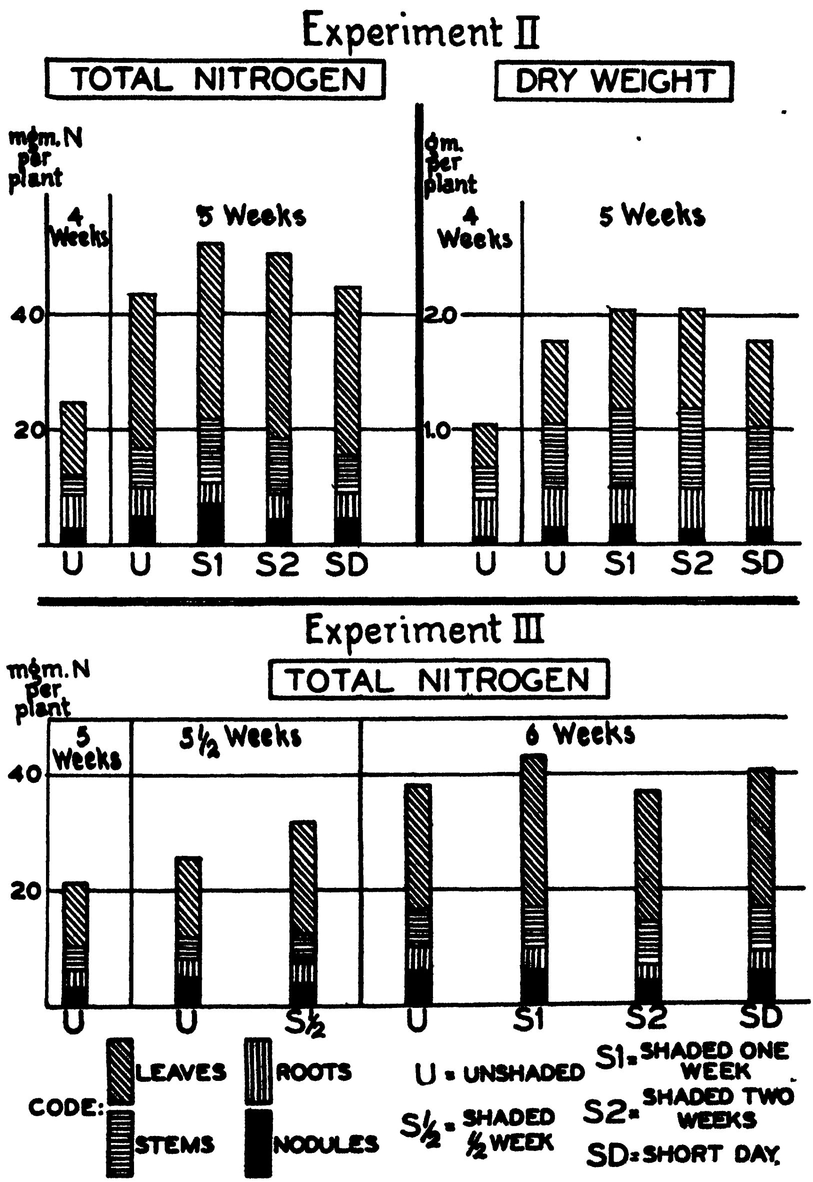

FIG. 3.—Effect of shading for short intervals on total nitrogen and dry weight of inoculated soybean plants.

under "4 weeks", represents the condition of these plants at the start of shading. The plants shaded 2 weeks showed 18%, or 6.5 mgm., more nitrogen fixed and 16% or 280 mgm., more dry weight per plant than unshaded controls. The short day plants showed no appreciable difference in dry weight or total nitrogen from the plants under normal conditions.

Experiment III was carried out in the middle to late summer under somewhat less light intensity than Experiment II. These data are plotted in the lower half of Fig. 3. The plants shaded 4 days and harvested at 5½ weeks showed 31%, or 5.8 mgm., more nitrogen per plant than the unshaded plants. The plants shaded 1 week and harvested at 6 weeks showed 4.4 mgm. more nitrogen per plant than the unshaded controls. The nitrogen in plants shaded 2 weeks in this experiment, however, was slightly less than controls (1.9 mgm); in this case carbohydrate probably became the limiting factor. The short day plants, as in Experiment II, showed no gain or loss in nitrogen over plants under normal conditions. No gains in dry weight were noted.

DISCUSSION

The shading of plants normally brings about a lower dry weight and sugar level than normal as found in the plants receiving nitrate in the first of these experiments. In the case of the inoculated soybeans, however, it was found that under normal high light intensity of early summer the plants were very slow in initiating the fixation process. As a result the plants had a high excess of carbohydrate as evidenced by the yellow leaves and anthocyanin formation in the stems. By partially reducing the light intensity an immediate growth response was noted in the plants as seen in Fig. 1, so that the dry weight and total nitrogen fixed were materially increased. It is a common observation that while soybeans grown in sand culture in the early summer undergo this nitrogen hunger period before fixation commences no such yellowing is noted in the late summer and fall; or at least such a corresponding condition in the fall is much less noticeable and of comparatively short duration. One of the outstanding differences in environmental conditions between early summer and fall is the difference in duration and intensity of light so that the differences noted might be ascribed to this factor. The average intensity in Madison in gram calories per square centimeter falls from 16,000 in June and July to 10,000 in September and 7,000 in October. The average daily sunlight in hours is 9.9 and 10.3 for June and July, respectively. The corresponding figures for September and October are 7.3 and 5.6, respectively. The amount of radiant energy in the fall, therefore, in much less than in the spring and early summer. The possibility that the nitrogen lag period noted in legumes may be due to this light factor is supported by evidence given in these experiments. Plants in the yellow, low nitrogen condition were virtually brought out of this starvation period by reducing the light intensity received by the plants; and in addition, plants under continually shaded conditions, as well as short day plants, did not enter this period of yellowing. The increases in nitrogen fixed and dry weight per plant substantiate these superficial observations.

A statistical treatment of data obtained in these three experiments gives further indication of the detrimental effect of extremely high carbohydrate within the plant. For each treatment within a given experiment, the following correlation coefficients were calculated: The relative *percentage of nitrogen* with (a) relative *nitrogen fixed per gram of nodular material*, (b) relative *nitrogen fixed per gram of plant material*, and (c) relative *nitrogen fixed per plant*. The first plants harvested in each experiment which were grown under normal light intensity were taken as the control (equals 100), and the relative values, referred to above, calculated.

Table 1 summarizes the data. For each correlation the statistic Z and its standard deviation were estimated, and the values or r corresponding to the values $Z \pm 2\sigma_Z$ determined (2). These values, given in the last two columns of the table, represent the probable range of r.

TABLE 1.—*Correlations between relative percentage of nitrogen and relative nitrogen fixed.*

Correlation between percentage nitrogen and	r	Z	Probable range of r	
			Upper	Lower
Relative mgm. N fixed:				
Per gram of plant material....	0.921	1.567	0.971	0.775
Per gram of nodules.	0.868	1.298	0.950	0.644
Per plant.	0.637	0.733	0.852	0.207

$n^1 = 17$. $\sigma_Z = 0.267$.

These values for r indicate that a high *positive* correlation exists between the relative percentage of nitrogen and the relative quantity of nitrogen fixed determined on the three bases. The correlation with relative mgm. of nitrogen per plant, although quite definitely positive, was significantly lower than the other two bases used.

The percentage of nitrogen may be taken as a *negative* index of the carbohydrate level so that the observed correlations may be used as derived correlations between nitrogen fixed and the carbohydrate level. Since the values of r show a high *positive* correlation between nitrogen fixed and nitrogen percentage, they indicate a high *negative* correlation between carbohydrate level and nitrogen fixed.

This appears to be a reversal of the findings of Fred and Wilson (3) whose data indicated a *positive* correlation between increasing carbohydrate and number of nodules; and since number of nodules is positively correlated with nitrogen fixed (6), it would be expected that increasing carbohydrate would also increase nitrogen fixation.

The discrepancy between the results of these various workers and the present experiments may be explained by the different carbohydrate-nitrogen ratios dealt with in the two different types of experiments. When the plant is relatively rich in nitrogen, the fixation may be increased by making more carbohydrate available for protein formation and bacterial requirements; but when the carbon-

nitrogen ratio becomes excessive the fixation is retarded if not completely inhibited. Fred and Wilson (3) suggest that the carbon-nitrogen ratio becomes so over-balanced that the "available nitrogen is tied up and thus retards the development of the fixation centers." It is further suggested that the high carbon-nitrogen ratio tends to produce a non-succulent plant and the carbohydrate is condensed in storage forms which are relatively unavailable for protein formation from any nitrogen which might be fixed. This hypothesis is supported by the observation, in the first experiment in particular, that the nodules on the nitrogen-deficient plants appeared to be as large and as well formed as those found on shaded plants where fixation was known to have taken place. It is suggested, then, that the high carbon-nitrogen ratio brings about a non-succulent plant whose translocatory powers are greatly diminished and whose carbohydrate has become relatively fixed in the tissues in a dehydrated, non-translocatory form.

It appears probable, from the evidence thus far presented, that neither high nor low carbon-nitrogen ratios favor fixation of nitrogen. On the other hand, there seems to be an optimum somewhere between these two extremes where the fixation activity is favored.

SUMMARY

1. Inoculated soybeans grown (in nitrogen-free sand) under normal high light intensity of early summer failed to initiate the process of nitrogen fixation. Partial shading for 1 week brought the plants out of this fixation lag period.

2. Experience from the work of two summers made it appear that this was correlated with the carbon-nitrogen relation within the plant. A statistical treatment of the data obtained in this type of experiment indicates a high *negative* correlation between the carbohydrate level and nitrogen fixed. It is concluded that an extremely *high* carbon-nitrogen ratio in the plant inhibits nitrogen fixation similar to the inhibition observed with extremely *low* carbon-nitrogen ratios.

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THE EFFECT OF CERTAIN FERTILIZER MATERIALS ON THE IODINE CONTENT OF IMPORTANT FOODS[1]

J. S. McHargue, D. W. Young, and R. K. Calfee[2]

IODINE is one of the less common non-metallic elements that is widely distributed in very small quantities in nature. Apparently, iodine is less abundant in its occurrence in nature than either bromine, chlorine, or fluorine; however, it has a very important physiological function in the metabolism of animals.

According to the literature, the ancient peoples of several countries had learned that certain marine plants and the tissues of some animals possessed curative properties in the treatment of goiter. After the discovery of iodine by Courtois (1)[3] in 1811, these substances were shown to contain considerable quantities of iodine. For example, the Chinese (2) are said to have burned seaweeds and sponges and fed the ash to persons afflicted with goiter about 3,500 years before the discovery of iodine. The early Greeks and Romans (2) are also said to have fed the thyroid gland from sheep and goats to patients afflicted with goiter.

In 1820, Coindet (3), a physician at Geneva, painted the throats of goiter patients with a tincture of iodine and observed that a few of them were apparently benefited while others were not.

In 1850, Chatin (4) pointed out that apparently goiter was more prevalent in certain areas of soil in France which contained the smallest amount of iodine. Soils deficient in iodine have been shown, in recent years, to occur in several other parts of the world.

In 1895, Baumann (5) discovered that iodine is concentrated in the thyroid gland and that this organ contains several times more of the element than any other tissue examined in the animal body. This discovery set a host of investigators to work in all civilized countries to ascertain the significance of the accumulation of iodine in the thyroid gland. It was not until 1915, however, that Kendall (6) succeeded in isolating the hormone, thyroxine, from the thyroid gland and proved that the pure substance contained 65% iodine. Other investigators have further proved that thyroxine performs a very important function in the metabolism of animals and that iodine is indispensable in the economy of both plants and animals.

Von Fellenberg and other investigators (7) estimate that the iodine requirement for an adult person is about 0.000014 gram per day. It is the consensus of opinion among investigators in this field

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[2]Head of Department and Assistant, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 565.

that the higher forms of animals can assimilate organic combinations of iodine better than the inorganic forms of this element. Accordingly, the question of whether or not normal foods contain an adequate amount of iodine is one of fundamental importance in the art of agriculture

Certain crude forms of fertilizer materials which occur in nature have been shown to contain a considerable quantity of iodine. For some time an investigation concerning the iodine content of certain fertilizer materials, limestone rocks, soils, forage crops, and foods produced in various parts of Kentucky has been under way at the Kentucky Agricultural Experiment Station Some of the results thus far obtained at our laboratory and elsewhere are shown in the following tables, the results being the averages of two or more closely agreeing determinations. Table 1 shows the iodine content of various fertilizer materials

TABLE 1.—*Iodine content of various kinds of fertilizer materials*

Fertilizer material	Iodine content in p p b	
	Minimum	Maximum
Superphosphate	104	5,700
Potassium sulfate	0	120
Potassium chloride	60	160
Basic slag	0	360
Ammonium sulfate	0	400
Limestone rocks	200	7,000
Rock phosphate (crude)	5,700	20,000
Chile nitrate (crude)	11,000	149,200
Stable manure*	—	1,000
Turnip manure*	—	5,400
Island phosphate*	—	4,200
Guano*	24,000	26,400

*Reported by Orr and Leitch (8).

The above results show that the iodine content of some fertilizers may vary widely However, crude Chile nitrate and raw rock phosphate contain relatively large amounts of the element and afford all the iodine necessary for the growth of plants and the production of foods on soils deficient in this element

TABLE 2 —*Summary of iodine content of Kentucky soil.*

Areas	No. of samples analyzed	Iodine in p.p.m.		
		Maximum	Minimum	Average
1. Purchase	42	6.93	1.59	4.57
2. W. Coal Field	69	7 37	2.31	4.11
3. Mississippian	100	16 95	2.53	6.10
4. O. Bluegrass	132	11 85	1.10	4.07
5. I. Bluegrass	64	8.25	2.40	4.35
6. E. Coal Field	14	3 08	0.80	2.05
Total	421	16 95	0.81	4.59

Six principal geological areas occur in Kentucky. Soils from each of these areas were analyzed by the combustion method for iodine. A summary of the results is shown in Table 2 (9).

It will be observed from the results in Table 2 that the soils in area 6, the Eastern Coal Fields, contained the smallest amount of iodine, therefore the iodine content of foods produced in this part of the state is of particular interest in connection with iodine study. Accordingly, samples of corn produced in several different counties of the Eastern Coal Field were obtained and analyzed for iodine The results are shown in Table 3

TABLE 3 —*Iodine in corn grown in 19 counties in eastern Kentucky, 1933.*

County	Fertilizer treatment	Yield, bu per acre	Iodine content in p p.b.
Boyd	Rich land + manure	54	68
Knox	———?	—?	87
Bell	200 lbs superphosphate	72	88
Madison	———?	30	88
Johnson	———?	30	90
Rockcastle	———?	80	103
Whitley	Manure + superphosphate	52	109
Powell	Limestone + superphosphate	65	111
Jackson	Limestone + 200 lbs 2-12-2 fert	80	120
Breathitt	———?	—?	120
Magoffin	Manure	135	123
Elliott	Manure	79	132
Letcher	300 lbs superphosphate	50	180
Clay	Limestone + superphosphate	80	200
Laurel	Limestone + superphosphate	56	212
Lee	Manure	55	220
Leslie	———?	—?	586
Morgan	3 8-6 fertilizer	60	720
Menifee	———?	—?	250,000

The bluegrass soils upon which were grown the samples of corn shown in Table 4 are derived from the disintegration of limestone rocks and some of them are rich in phosphorus However, the iodine

TABLE 4 —*Iodine content of corn produced on untreated bluegrass soils in 1934.*

Soil No	Iodine content in p p.b.
Bourbon County	
1	720
2	423
3	480
4	483
Fayette County	
1	144
2	132
3	176
4	189
5	151
6	144
7	206
Garrard County	
1	1,750

content of the corn apparently was not affected very much by soils that contained relatively large amounts of phosphorus.

In the first 12 samples given in Table 3, the iodine content averages 103 p.p.b. It may be assumed that where fertilizers were used on these 12 samples they contained relatively small amounts of iodine. Apparently corn that contains 100 p.p.b. of iodine or less is to be regarded as deficient in this element. The average yield for 10 of the first 12 counties was 67.7 bu. per acre.

Samples of corn from the next four counties gave an average of 203 p.p.b. of iodine and the average yield for these counties was 60.2 bu. Apparently, the iodine content of these four samples of corn was affected appreciably by the fertilizers used.

The samples of corn from the next two counties, Leslie and Morgan, have an average iodine content of more than 6 times the average of the first 12 samples and more than 3 times the average of the next four samples. Accordingly, the iodine content of the samples of corn from Leslie and Morgan counties was also affected by fertilizer treatment.

The sample from Menifee County is of unusual interest because of the very large amount of iodine it contained. This corn was reported to have been grown by a member of a 4-H Club and thus far we have not succeeded in obtaining information as to what kind and how much fertilizer was used in producing it. However, for the present discussion, we are assuming that a fertilizer containing considerable iodine, either sodium nitrate or rock phosphate, or both, was used in growing this corn. The sample received consisted of approximately 5 pounds of apparently normal grains of yellow corn. Previous to the analysis of this sample, it had not occurred to us that it would be possible to increase the iodine content of corn to such a high level. Expressed in per cent, this corn contained 0.025% iodine, or approximately 1/10 as much iodine as is contained in seaweeds. An average size grain of Reed's Yellow Dent field corn weighs approximately 0.4 gram. Assuming that the average person requires 0.000014 gram of iodine per day, as stated by von Fellenberg, one grain of the sample of corn from Menifee County, if divided into 7 equal parts, would supply as many adult persons with their daily iodine requirement.

Plants absorb inorganic salts and synthesize organic combinations from them. It occurred to us that possibly the corn plants, in this case, might have absorbed a relatively large amount of an inorganic iodine compound and stored it in the seed unchanged. However, tests by dialysis with water and alcohol proved that the iodine was in organic combination and therefore in the proper form for assimilation when used as food for animals. Other tests by which different protein fractions were separated showed that iodine was in combination with all of the fractions thus separated. The fat, protein, and ash content of the high-iodine corn were normal. Furthermore, this sample of corn indicates a way of producing an edible food high in iodine organically combined for livestock and man.

Thru the cooperation of the Agronomy Department of the Experiment Station, we were able to obtain 18 samples of wheat grown in

1932 with various fertilizer treatments at the Fariston Experiment Field, located in the southeastern part of the state. The results for iodine in these samples of wheat are shown in Table 5.

TABLE 5.—*Iodine content of 18 samples of wheat produced on the same field but with different fertilizer treatments, composite samples.*

No. of sample	Treatment	Iodine in p.p.b.
C-812	Check plats	425
C-813	Manure	392
C-814	Rock phosphate + finely ground limestone	700
C-815	Manure + rock phosphate + finely ground limestone	773
C-816	Rock phosphate	720
C-817	Manure + rock phosphate	580
C-818	Superphosphate	615
C-819	Nitrogen + superphosphate	525
C-820	Phosphorus + potassium	690
C-821	Manure + phosphorus + potassium	425
C-822	Phosphorus + potassium + nitrogen	1,330
C-823	Manure + phosphorus + potassium + nitrogen	450
C-824	Limestone + superphosphate	375
C-825	Nitrogen + limestone + superphosphate	450
C-826	Limestone + rock phosphate	790
C-827	Manure + limestone + rock phosphate	500
C-828	Phosphorus + potassium + nitrogen	676
C-829	Manure + phosphorus + potassium + nitrogen	755

The iodine content of the check sample was 425 p.p.b., the maximum 1,330 p.p.b., and the average of the 17 treated samples, 620 p.p.b. These results show a rather wide variation in the iodine content of wheat grown on the same field and suggest that the differences are due to variation in the iodine content of the fertilizers used.

During the summer of 1934 an experiment was carried on in which varying quantities of potassium iodide were added to the soil on which corn plants were grown. At different times during the growing season and at maturity the plants or the grain produced were analyzed for iodine. The results of the different treatments are given in Table 6.

TABLE 6.—*Iodine content of corn grown in soil to which increasing amounts of potassium iodide were added during the growing season.*

Material	No.	Iodine added per plant, grams	Iodine found in p.p.b.
		June 20, 1934	
Young plants	1	0.10	12,000
Young plants	2	0.18	15,000
Young plants	3	0.27	28,000
Young plants	4	0.36	33,000
Young plants	5	0.90	34,000
		July 27, 1934	
Young leaves	1	0.27	20,000
Young leaves	2	0.54	13,000
Young leaves	3	0.81	30,000
Young leaves	4	1.08	10,000
Young leaves	5	2.70	34,000

TABLE 6—*Continued*

Material	No	Iodine added per plant, grams	Iodine found in p p b
		Aug. 17, 1934	
Leaves	1 White	0.33	4,000
Leaves	2 White	0 66	6,000
Leaves	3 White	0 99	10,000
Leaves	4 White	1 32	14,000
Leaves	5 White	3 30	26,000
Leaves	1 Yellow	0 33	4,000
Leaves	2 Yellow	0 66	6,000
Leaves	3 Yellow	0 99	10,000
Leaves	4 Yellow	1 32	6,800
Leaves	5 Yellow	3 30	11,000
Grain	1 White	0 33	2,000
Grain	2 White	0 66	7,000
Grain	3 White	0 99	11,000
Grain	4 White	1 32	11,000
Grain	5 White	3 30	24,000
Grain	1 Yellow	0 33	2,000
Grain	2 Yellow	0 66	6,000
Grain	3 Yellow	0 99	11,000
Grain	4 Yellow	1 32	15,000
Grain	5 Yellow	3 30	25,000
Stalk	1 White	0 33	4,000
Stalk	2 White	0 66	5,000
Stalk	3 White	0 99	6,000
Stalk	4 White	1 32	11,000
Stalk	5 White	3 30	14,000
Stalk	1 Yellow	0 33	3,000
Stalk	2 Yellow	0 66	5,000
Stalk	3 Yellow	0 99	11,000
Stalk	4 Yellow	1 32	10,000
Stalk	5 Yellow	3 30	18,000
		Nov 5 1934	
Grain	1 White	0 42	310
Grain	2 White	0 84	416
Grain	3 White	1 26	670
Grain	4 White	1 68	880
Grain	5 White	4 20	2,700
Grain	1 Yellow	0 42	400
Grain	2 Yellow	0 84	570
Grain	3 Yellow	1 26	760
Grain	4 Yellow	1 68	1,200
Grain	5 Yellow	4 20	2,400
Exp. Sta. Farm grain	White	Untreated	178
Exp. Sta Farm grain.	Yellow	Untreated	192

SUMMARY

1. Crude Chile nitrate, raw rock phosphate, and limestone rocks may contain enough iodine to influence the iodine content of forage crops and vegetables when applied in adequate amounts to soils deficient in iodine.

2. Plants may absorb relatively large amounts of iodine without producing any signs of toxicity

TABLE 7.—*Iodine content of vegetables.*

Kind of vegetable	Check plat, iodine in p.p.m.	Treated vegetables, iodine in p.p.m.	Ratio of increase
Beet tops	0.6	237	395
Cabbage	0.5	280	560
Lettuce	0.4	91	228
Onion bulbs	—	400	—
Onion tops	—	800	—
Pumpkin	0.2	10	50
Spinach	3.2	532	166
Tomato (fruit)	0.2	30	150

3. It is a simple matter to increase the iodine content of forage crops and vegetables by adding appropriate amounts of potassium iodide to the soil in which they are grown.

4. Tests by dialyses and the separation of various protein fractions of a sample of corn that contained a relatively large amount of iodine showed that this element was present in organic combinations and therefore in suitable form for assimilation by livestock and man.

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THE KILLING EFFECT OF HEAT AND DROUGHT ON BUFFALO GRASS AND BLUE GRAMA GRASS AT HAYS, KANSAS[1]

D. A. SAVAGE AND L. A. JACOBSON[2]

THE short grasses, buffalo grass (*Buchloe dactyloides* (Nutt.) Engelm.) and blue grama grass (*Bouteloua gracilis* (H. B. K.) Lag.), are considered very drought resistant and fully adapted to the driest sections of the central Great Plains where they constitute the principal native vegetation. This has been expressed or implied by numerous investigators, including Lyon and Hitchcock (7)[3], Shantz and Zon (13), Shantz (12), Aldous and Shantz (1), and Savage (9, 10). Shantz (11) reported that "the principal adaptation of these short grasses to arid conditions lies in their ability to dry out (become dormant) and to revive quickly when water is again supplied."

Other drought-enduring characters of these grasses include extensive fine-branched root systems, agressive low-growing aerial parts, and the ability of the leaf blades, as shown by Weaver and Fitzpatrick (16), to limit transpiration by rolling tightly during periods of stress. In reference to the prairie grasses of eastern Nebraska, Weaver and Himmel (18) stated that "a few relics of the drier climates, e. g., *Bouteloua gracilis* and *B. hirsuta* withstood the drought (of 1930) best." Sarvis (8) reported that dry seasons were no doubt responsible for a reduction in the size of mats of *B. gracilis* at Mandan, N. D.

Although reports have been made by Weaver and Harmon (17) and by Wilkins (19) on the killing effect of drought on *Poa pratensis*, and by Gates (4) on other classes of vegetation, the writers found no published information to indicate that the short grasses of the plains were ever fatally injured by drought. It became apparent, however, that many of the short-grass plants in the vicinity of Hays, Kans., had been damaged beyond recovery by the record-breaking heat and drought of 1933–34.

In order to determine the local extent of the injury under different systems of grazing and lawn management, an investigation was conducted on the Fort Hays (Kansas) Branch Experiment Station in the fall of 1934. A summary of climatic conditions prevailing during the drought period is essential to a clear understanding of the problems involved in this study.

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[1]Contribution from the Fort Hays Branch of the Kansas Agricultural Experiment Station, Hays, Kans., and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating.

[2]Assistant Agronomist and Agent, respectively, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture; in direct charge and assistant, respectively, of forage crops experiments at the Fort Hays Branch Experiment Station, Hays, Kans. The writers are indebted for assistance rendered in the preparation of this paper by their colleagues in the Bureau of Plant Industry and the Kansas Agricultural Experiment Station and others, particularly Prof. F. W. Albertson and Dr. A. W. Barton of the Fort Hays Kansas State College.

[3]Figures in parenthesis refer to "Literature Cited," p. 582.

CLIMATIC CONDITIONS

The 1933–34 biennium was the hottest and driest on record at Hays, Kans., since 1894–95, Table 1. A nearly continuous period of intensive drought, interspersed at wide intervals by generally ineffective light or torrential showers and characterized by high temperatures, hot winds, and excessive evaporation during the growing seasons, prevailed in this locality from October 21, 1932, to August 30, 1934. Daily precipitations have been recorded here since 1868; daily air temperatures since 1893; daily evaporations from a free-water surface for the growing seasons since 1907; and daily wind velocities for the growing seasons since 1908[4].

Precipitation.—The annual precipitation was 16.26 inches in 1933 and 16.06 inches in 1934, as compared with an average of 22.88 inches for the 67-year period, 1868 to 1934. The precipitation for the last 2 months of 1932, the first 11 months of 1933, and 9 months in 1934 was below the average.

Temperatures.—Each of the last two summers was the hottest on record in this locality. The average maximum air temperature for the six-month period, April to September, was 86.1° F in 1933 and 88.6° in 1934, as compared with a 42-year average of 82.8°. In 1934 the average maximum and mean temperatures for May, June, and July were the highest ever recorded here, and those for August were the second highest. The June temperatures in 1933 were exceeded only by those for the same month in 1934. During the latter year the daily air temperatures exceeded 100 degrees on 4 days in May, 10 days in June, 24 days in July, and 15 days in August, reaching a 42-year maximum of 117 degrees in July.

Evaporation.—As mentioned by Weaver and Himmel (18) and Hursh and Haasis (6), "the rate at which water evaporates integrates and shows quantitatively" the combined effect of various climatic factors. The highest evaporation recorded here for the growing season, April to September, inclusive, was that of 66.024 inches in 1934, which may be compared with 56.453 inches in 1933 and 47.683 inches as the average for 28 years. With the exception of August, 1933, and September, 1934, the total evaporation for every month of the growing season during the last two years was decidedly above average. In 1934 the monthly evaporation for May and July exceeded all previous extremes for those months.

Wind velocity.—The wind movement was not unduly high in 1933 but was decidedly above the 27-year average in May, June, and August of 1934.

Frost-free period.—For the 43-year period ending with 1934, the average dates of the last killing frost in the spring and the first in the fall were April 29 and October 13, respectively, which represent an average growing season of 167 days. In 1934 the first killing frost in the fall occurred on October 28. This enabled grasses revived by rather substantial rains in late summer to continue growth until that date.

LOCATION OF INVESTIGATIONS

Locations selected for quadrat studies of the drought effect included: (a) A closely grazed and severely tramped area, (b) a moderately grazed area, (c) dry land lawns, (d) lightly watered lawns, and (e) heavily watered lawns. The pastures are illustrated in Fig. 1 and the lawns in Fig. 2. Both pasture areas were grazed moderately before the drought, but area (a) was grazed closely during the

[4]The writers are indebted to the U. S. Weather Bureau and the Division of Dry Land Agriculture, U. S. Dept. of Agriculture, for providing the basic climatic records from which these summaries were made, and to A. L. Hallsted of the latter agency, who has kept these records since 1908.

TABLE 1.—*Summary of climatological observations at the Fort Hays (Kansas) Branch Experiment Station for 1933 and 1934, compared with averages or totals for the 67-year period, 1868 to 1934.*

Years or period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Seasonal, Apr. 1 to Sept. 30	Annual
Precipitation in Inches														
For 1933	0.07	0.21	0.33	2.14	2.82	1.07	2.12	2.73	2.03	0.03	0.54	2.17	12.91	16.26
For 1934	0.29	1.16	0.45	0.37	1.55	5.15	0.54	2.78	2.48	0.52	0.75	0.02	12.87	16.06
Av. 1868 to 1934	0.49	0.82	1.00	2.29	3.22	3.45	3.22	3.03	2.30	1.48	0.83	0.75	17.51	22.88
Evaporation in Inches from a Free-water Surface														
For 1933	—	—	—	6.850	6.990	12.875	12.442	8.896	8.400	—	—	—	56.453	—
For 1934	—	—	—	6.912	10.740	12.645	16.322	12.824	6.581	—	—	—	66.024	—
Av. 1907 to 1934	—	—	—	5.751	6.845	8.395	10.139	9.235	7.318	—	—	—	47.683	—
Wind Velocity in Miles per Hour														
For 1933	—	—	—	9.6	8.6	8.3	6.8	6.6	7.8	—	—	—	8.0	—
For 1934	—	—	—	9.1	10.1	9.8	10.0	8.3	9.8	—	—	—	9.5	—
Av. 1908 to 1934	—	—	—	10.2	8.8	7.7	6.0	6.6	7.6	—	—	—	8.0	—

Air Temperatures in Degrees, F

Absolute maximum:														
For 1933	67	71	82	87	96	112	113	108	101	85	93	74	113	113
For 1934	70	72	82	91	103	105	117	112	99	99	83	56	117	117
For 1893 to 1932	78	84	97	99	104	114	110	110	111	98	87	78	114	114
Absolute minumim:														
For 1933	11	—23	11	19	36	51	52	55	37	26	18	6	19	—23
For 1934	9	— 6	5	23	40	52	52	48	32	25	22	3	23	— 6
For 1893 to 1932	—23	—24	—10	2	17	31	37	36	20	9	—6	—21	2	—24
Average maximum:														
For 1933	54.6	46.3	62.2	66.3	77.3	97.2	96.3	90.4	89.0	73.6	62.0	53.1	86.1	72.4
For 1934	49.3	48.0	59.6	71.6	85.5	94.7	103.6	97.1	78.8	77.4	59.4	43.2	88.6	72.4
Av. 1893–1934	42.5	46.4	57.2	67.6	75.7	86.0	92.5	91.5	83.5	71.2	56.2	44.4	82.8	67.9
Average minimum:														
For 1933	21.1	12.5	31.3	40.9	49.2	64.3	66.7	63.9	59.1	41.3	30.3	24.4	57.4	42.1
For 1934	23.0	21.2	26.1	39.8	55.1	65.3	70.6	67.5	51.1	46.2	33.3	20.3	58.2	43.3
Av. 1893–1934	16.5	18.2	27.0	38.3	48.9	59.0	64.1	62.7	54.1	40.7	27.5	18.3	54.5	39.6
Mean:														
For 1933	37.9	29.4	46.8	53.6	63.3	80.8	81.5	77.2	74.1	57.5	46.2	38.8	71.8	57.3
For 1934	36.2	34.6	42.8	55.7	70.3	80.0	87.1	82.3	65.0	61.8	46.4	31.8	73.4	57.8
Av. 1893–1934	29.8	32.2	42.1	53.0	62.3	72.5	78.4	77.1	68.8	56.0	41.8	31.6	68.7	53.8

Killing Frosts

	Last in spring	First in fall	Frost-free period, days
For 1933	Apr. 16	Oct. 8	175
For 1934	Apr. 13	Oct. 28	198
Av. 1892 to 1934	Apr. 29	Oct. 13	167

drought and was subjected to severe tramping by livestock. This area, therefore, is considered to be comparable with many continuously overgrazed pastures in this vicinity. The lawns represented a part of the station campus which was clipped periodically with a mowing machine and was not watered previous to the

FIG. 1.—A moderately grazed native short-grass pasture on the Fort Hays Branch Station, showing typical mixtures of wire grass in the foreground and *Psoralea tenuiflora* in the background. The surface growth of the latter breaks off and blows away in late summer, leaving a smooth expanse of short grass broken at intervals by tufts of wire grass. Photographed at Hays, Kans., July 10, 1934.

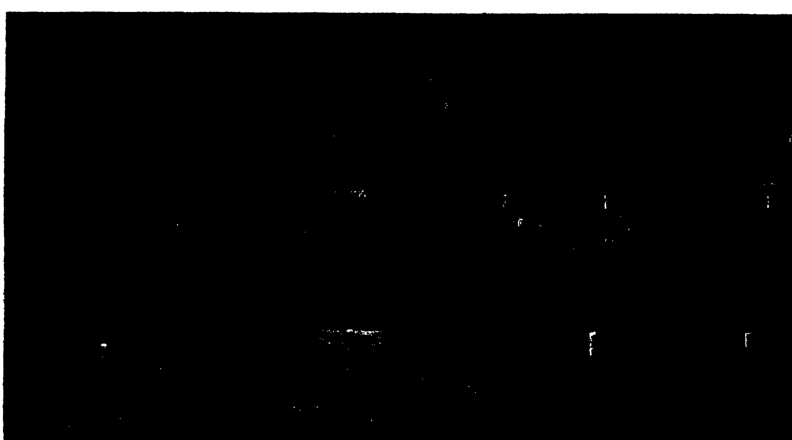

FIG. 2.—Eighteen lawn plats of native short grass clipped at varying heights and at different times in 1934. Plats in the foreground and in the right row are not watered, while those in the left row are watered heavily and in the middle row, lightly. Photographed at Hays, Kan., September 5, 1934.

drought. Beginning in the spring of 1934, 18 lawn plats were laid out and clipped continuously at different heights with lawn mowers. Some of them were watered heavily, some lightly, and some received no water.

Although the mixed prairie grasses are present to some extent in this region, the principal native pasture vegetation consists of the typical short-grass associes with scattering mixtures of other vegetation, including *Psoralea tenuiflora*, *Aristida purpurea*, and *Andropogon scoparius*. General observations before the drought indicated that the areas selected for study were almost completely occupied by buffalo grass and blue grama grass. The former appeared to predominate on grazed and other clipped areas. The stoloniferous habit of this species may account for the large basal cover noted.

APPEARANCE OF GRASS IN THE FALL OF 1934

All short-grass pastures and lawns in the immediate vicinity of Hays, Kans., assumed a bright green color in the fall of 1934, after 2.20 inches of rain were received from August 31 to September 3, followed by additional showers totaling 1.33 inches during the remainder of September, and 0.52 of an inch before frost occurred in October. Temperatures and evaporation in September were low compared with extremes for the previous months and represented conditions especially favorable for the growth of grasses. Casual observation indicated that the grass had survived the drought fairly well. Numerous weed seedlings and other growth masked the injured areas and contributed to the general green appearance as viewed from a distance. These included *Hordeum pusillum*, *Allium nuttallii*, *Sporobolus cryptandrus*, *Carex heliophila*, and *Cymopterus acaulis*. Close and repeated inspection, however, showed that an alarming number of the short-grass plants had failed to revive. Overgrazed and severely tramped pastures appeared to have suffered the most, although numerous dead plants were apparent on moderately grazed pastures and dry land lawns. Much local concern was expressed over this unprecedented condition, which prompted the inauguration of careful studies to ascertain the extent of the damage.

Before measuring the injured areas it was considered important to determine as accurately as possible if the unrevived plants were actually dead or merely in an unusually advanced stage of dormancy. The aerial portions of the apparently dead plants had every appearance of being dead. Large areas of the sod were transferred to a green house where the plants judged to be dead failed to revive, while those known to be alive grew vigorously. The live buffalo grass plants in the field produced many new stolons, ranging in length from 4 to 17 inches, before the first killing frost caused a cessation in growth on October 28.

Shantz (11) reported that drought-dormant plants of buffalo grass and grama grass are capable of renewing growth after the soil has been moistened to a depth of a few inches by a small shower. Observations by the senior author for a period of 6 years at Hays, Kans., substantiate this report. Although these statements and the facts mentioned above may not be positive proof that all live plants had renewed growth in the fall, the combined evidence indicates rather definitely that such was the case.

MATERIALS AND METHODS

Permanent quadrats were established and definitely marked off with a rigid slat-iron frame 1 meter square. Double holes were bored adjacent to decimeter markings on two sides of the frame. Two cross slats, similarly marked in decimeters

and having holes at both ends to match those on the frame, were moved alternately on the frame to assist in outlining the areas in each decimeter strip.

Since the vegetation consisted mostly of short well-defined mats, a pantograph was used to chart the basal cover of grass in the different areas (Fig. 3). The basal cover represented the amount of ground surface actually covered by the nearly pure stands of short grass after most of the foliage had been removed by the grazing or clipping treatments. The short foliage cover present made it possible to delimit the matted areas with considerable accuracy. This foliage, however, doubtless caused the results to show somewhat larger coverage than would have been obtained if all of the surface vegetation had been removed, thus exposing the surface limits of growth to more precise charting. The interlacing net-work of buffalo grass stolons was considered a part of the basal cover.

FIG. 3.—Illustrating the pantograph method of charting native short grass on a lawn plat clipped 2 inches high and watered heavily in 1934. Note the cross-wired, list quadrat frame in the background. Photographed on the Fort Hays Branch Station, Hays, Kans., September 10, 1934.

Each chart was reduced to an area 1/25th that of a square meter or by a lineal ratio of 5 to 1. This reduction is less than that made by a number of investigators, including Steiger (14), and is, therefore, considered by the writers to minimize the error recognized to be present in pantograph charting.

The pantograph was constructed with certain improvements over that discussed by Hanson and Love (5). It was fastened to a drawing board which was laid on the ground adjacent to the meter frame. Errors in operation were reduced in this manner by having the pantograph resting on practically the same plane as the grass. The edges of the grass could be followed with the inch-long pointer without changing the angle between the tip of the pointer and the arm of the pantograph. This eliminated errors due to the use of a long pointer. One operator followed instructions from the man who moved the pointer, and outlined the areas on the chart by raising and lowering a pencil in a hollow tube fastened to the proper location on the pantograph. Each area of grass was properly and simultaneously designated on the chart by means of a second pencil.

In this manner, 54 meter quadrats were charted to show live short grass, dead short grass, *Aristida purpurea*, *Andropogon scoparius*, and bare ground. Twelve of the quadrats were located on closely grazed areas, 6 on moderately grazed areas, 16 on variously clipped dry land lawns, 10 on lightly watered lawns, and 10 on heavily watered lawns. During the winter the pencil sketches of each chart

were inked in, cross hatched to distinguish each type of vegetation represented, and measured with a planimeter. The resultant data were computed to determine the percentage of mortality, percentage of ground cover, and other factors under consideration.

RESULTS

The information obtained from these studies is presented and interpreted with the fairly reliable assumption that all live plants had renewed growth in the fall. Statements justifying or substantiating this belief are included in the foregoing discussion. Since, unfortunately, no quadrat studies were made before the drought, the total ground cover at that time is assumed to have been practically complete. This assumption is based, not only upon superficial observations before the drought, but upon careful charting of the dead and live growth after the drought. These combined results are considered to represent the actual cover of live growth before the drought.

It is not unusual for grasses of a turf-forming or stoloniferous nature to make nearly a perfect basal cover. Shantz (11) reported that the buffalo-blue grama grass associes often "covers practically the whole surface of the ground". In discussing the results of unpublished data obtained at Beltsville, Md., and Kylertown, Pa., Vinall (15) stated that "with the stoloniferous grasses, it is entirely possible here in the East to obtain a coverage of 95 to 100% as you do in the range areas with buffalo grass and grama grass".

Table 2 gives the average percentages of short-grass plants killed by the heat and drought of 1933–34 on local pastures and dry land lawns in comparison with the percentage of dead plants on lawns watered only in 1934. The average mortality was 74.8% on closely grazed and heavily tramped areas (Fig. 4), 64.6% on moderately grazed areas (Fig. 5), and 44.4% on dry land lawns (Fig. 6).

DROUGHT EFFECTS AGGRAVATED BY GRAZING

The high death rate on ungrazed lawns indicates that climatic conditions were primarily responsible for the mortality on all areas. The results show, however, that close grazing and tramping were indirectly accountable for the death of many plants. Under ordinary conditions the short grasses may be grazed closer and with less injury than practically any other class of vegetation. Shantz (11) stated that "ordinary grazing does not appreciably modify but somewhat favors the development of pure short-grass cover". In discussing results now being assembled for publication, Mathews[5] reports that "vegetation of the (short-grass) type prevailing in pastures at Ardmore, S. D. is not likely to be damaged without being grazed so closely that the animals grazing it suffer severe losses in weight". Hansen and Love (5) found that "buffalo grass may be favored under continuous grazing" and that "overgrazed wheat grass is replaced by blue grama grass" in Colorado.

The results here reported for Hays, Kans., indicate, however, that there is danger of heavy plant mortality occurring when short-grass

[5]Associate Agronomist, Division of Dry Land Agriculture, Bureau of Plant Industry, U. S. Dept. of Agriculture.

pastures are grazed either moderately or intensively during prolonged periods of intense heat and drought.

TABLE 2 —*Average mortality of native grasses (buffalo and blue grama) during the heat and drought of 1933–34 on pastures and dry land lawns, compared with the percentage of dead plants on lawns watered only in 1934.*

Grazing and clipping treatment	No of quadrats represented in averages	Average percentage of original short-grass cover		
		Killed by the drought of 1933–34	Dead plants after watering only in 1934	Difference due to watering only in 1934*
Pastures				
Closely grazed and heavily tramped	12	74 8		
Moderately grazed and lightly tramped		64 6		
Dry Land Lawns				
Clipped ½ in in 1934	2	42 1	—	—
Clipped 1¼ in in 1934	8	44 3	—	—
Clipped 2 in in 1934	2	52 7	—	—
Cut twice 1¼ in in 1934	2	48 3	—	—
Not cut in 1934	2	35 1	—	—
Grand av dry land lawns	16	44 4	—	—
Lightly Watered Lawns				
Clipped ½ in in 1934	2	—	4 9	37 2
Clipped 1¼ in in 1934	2	—	10 6	33 7
Clipped 2 in in 1934	2	—	14 2	38 5
Cut twice 1¼ in in 1934	2	—	25 0	23 3
Not cut in 1934	2	—	18 1	17 0
Grand av lightly watered lawns	10	—	14 5	29 9
Heavily Watered Lawns				
Clipped ½ in. in 1934	2	—	0 3	41 8
Clipped 1¼ in in 1934	2	—	2 3	42 0
Clipped 2 in in 1934	2	—	5 1	47 6
Cut twice 1¼ in in 1934	2	—	6 7	41 6
Not cut in 1934	2	—	11 2	23 9
Grand av heavily watered lawns	10	—	5 1	39 4

*Comparing the watered lawns with the dry land lawns similarly clipped.

EFFECTS OF WATERING DURING THE DROUGHT

Repeated applications of water in 1934 were decidedly beneficial in overcoming the effects of the drought of 1933 and in counteracting similar conditions in 1934 Ten quadrats on five lightly watered and variously clipped lawns showed that an average of 14 5% of the short grasses failed to survive (Fig 7) A like number of quadrats on heavily watered and similarly clipped plats revealed an average of 5.1% dead plants at the end of the 1934 season (Fig. 8). The former

plats received nine applications of water, or a total of 7.2 inches per plat, during the season. This was sufficient to keep the grass green throughout most of the ordinary growing period. The heavily watered plats received approximately twice as much water at each application, or a total of 15.6 inches per plat. The water was measured with a standard water meter and every plat in each watering treatment received the same amount at each application.

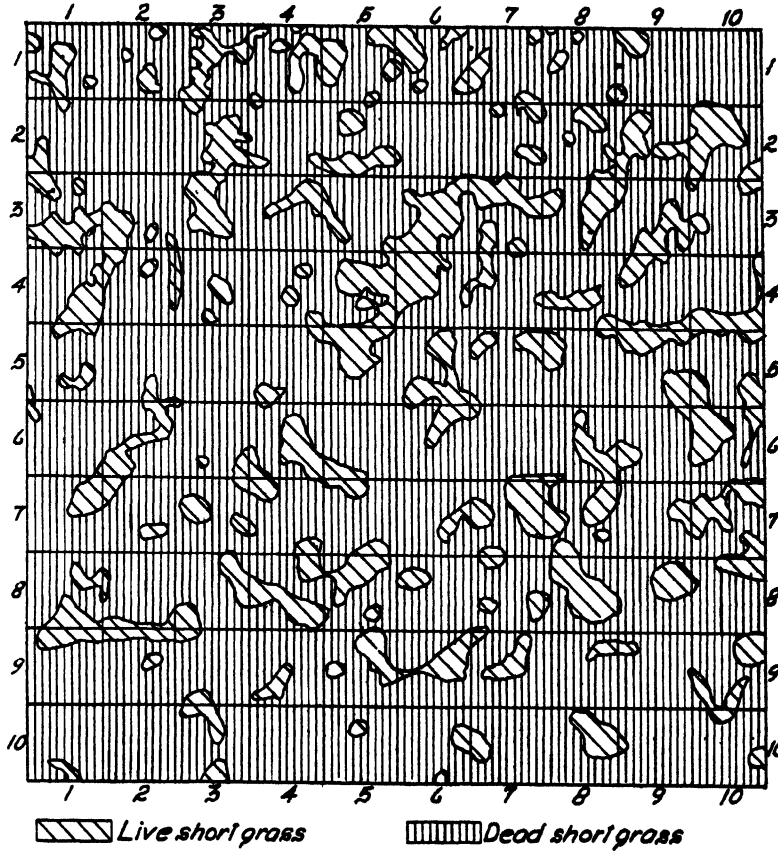

FIG. 4.—Meter quadrat No. 40 in a closely grazed area, showing 77.7% of the short-grass plants killed by heat and drought.

Late in the fall the soil moisture content on all plats, including those receiving no water, was uniformly low. This was revealed by duplicate 1-foot samples taken in November to a depth of 10 feet. These results indicate that water was not applied in excess of the needs of the grass.

BASAL COVERAGE AS AFFECTED BY DROUGHT

The average percentages of ground surface covered by short grasses on the different grazing and lawn treatments before the

drought, after the drought, and after applying water in 1934 are summarized in Table 3. The basal coverage before the drought, as computed from quadrat measurements of live and dead growth after the drought, ranged from 96.5 to 100%. The average of all quadrats was slightly more than 99%.

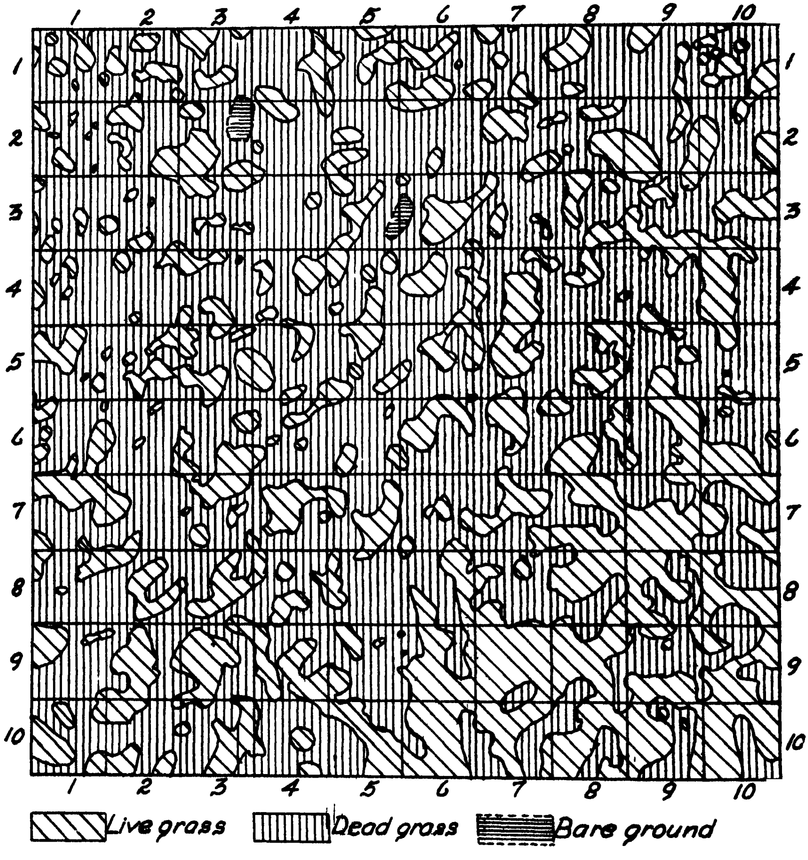

FIG. 5.—Meter quadrat No. 53 in a moderately grazed area, showing 65.6% of the short-grass plants killed by heat and drought.

After the drought the average coverage of live plants was 25.2% in the closely grazed areas, 35.4% in the moderately grazed areas, and 54.9% in the dry land lawns. The helpful effect of watering is further indicated by final basal coverages of 86.0% on the lightly watered lawns and 93.9% on the heavily watered lawns. The average difference in percentage of ground cover between the non-watered and lightly watered plats, similarly clipped, was 29.9% and the difference between the non-watered and heavily watered plats was 29.4%.

TABLE 3.—*Average ground surface covered by native short grasses (buffalo and blue grama) on pastures and lawns at the Fort Hays (Kansas) Branch Experiment Station before the drought of 1933–34, after the drought, and after applying water only in 1934.*

Grazing or clipping treatment	No. of quadrats represented in averages	Average total area covered by live short grasses			
		Before the drought of 1933–34 %	After the drought of 1933–34 %	After watering only in 1934 %	Difference due to watering only in 1934* %
Pastures					
Closely grazed and heavily tramped	12	99.5	25.2	—	—
Moderately grazed and lightly tramped	6	99.8	35.4	—	—
Dry Land Lawns					
Clipped ½ in. in 1934	2	96.7	56.0	—	—
Clipped 1¼ in. in 1934	8	99.6	55.4	—	—
Clipped 2 in. in 1934	2	99.1	46.9	—	—
Cut twice 1¼ in. in 1934	2	99.1	51.3	—	—
Not cut in 1934	2	99.7	64.7	—	—
Grand av. dry land lawns	16	99.1	54.9	—	—
Lightly Watered Lawns					
Clipped ½ in. in 1934	2	99.5	—	98.4	42.4
Clipped 1¼ in. in 1934	2	100.0	—	89.5	34.1
Clipped 2 in. in 1934	2	99.3	—	85.2	38.3
Cut twice 1¼ in. in 1934	2	99.8	—	74.9	23.6
Not cut in 1934	2	100.0	—	81.9	17.2
Grand av. lightly watered lawns	10	99.7	—	86.0	31.1
Heavily Watered Lawns					
Clipped ½ in. in 1934	2	100.0	—	99.7	43.7
Clipped 1¼ in. in 1934	2	99.8	—	97.5	42.1
Clipped 2 in. in 1934	2	97.4	—	92.5	45.6
Cut twice 1¼ in. in 1934	2	99.9	—	93.2	41.9
Not cut in 1934	2	97.8	—	86.9	22.2
Grand av. heavily watered lawns	10	99.0	—	93.9	38.8

*Comparing the watered lawns with the dry land lawns similarly clipped.

DROUGHT INJURY IN RELATION TO CLIPPING

The effects of different heights of clipping for 1 year on drought injury and basal cover are shown in the tables previously mentioned. These results support in general the findings of previous investigations by Savage (9, 10), which showed that moderate clipping to control the shading effect of tall grasses and weeds favors the spread of buffalo grass. Survival from heat and drought on all quadrats included in the averages presented increased in direct proportion to the closeness of clipping. Dry land plats clipped continuously in 1934

to maintain the growth at a height of ½ inch showed a lower percentage of dead plants and a correspondingly higher percentage of ground cover at the end of the drought than did those clipped at a

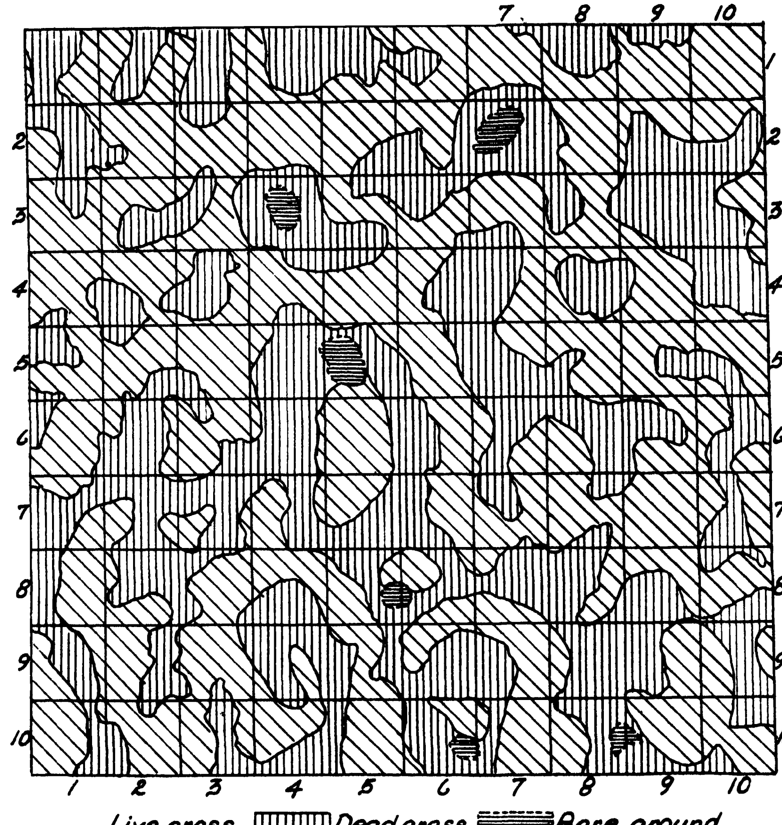

FIG. 6.—Meter quadrat No. 3 on a dry land lawn clipped 1¼ inches high in 1934, showing 43.5% of the short-grass plants killed by heat and drought.

height of 1¼ inches. The latter, likewise, were injured less and had more basal cover than those clipped at a height of 2 inches.

It should be definitely understood that these results were obtained from clippings made at various heights for only 1 year. Continued close clipping may show a reduction in the spread of the plants similar to that reported by Aldous (2) for the prairie grasses of eastern Kansas. The fact that close clipping for one season was helpful while close grazing for a longer period was detrimental is partly explained by the report of Culley, Campbell, and Canfield (3) that "clipping does not simulate actual grazing."

There was a similar positive correlation between closeness of clipping and recovery due to watering. The lightly watered plats clipped at a height of ½ inch, 1¼ inches, and 2 inches showed average

basal covers of 98.4%, 89.5%, and 85.2%, respectively. Heavily watered plats similarly clipped had average basal covers of 99.7% 97.5%, and 92.5%, respectively.

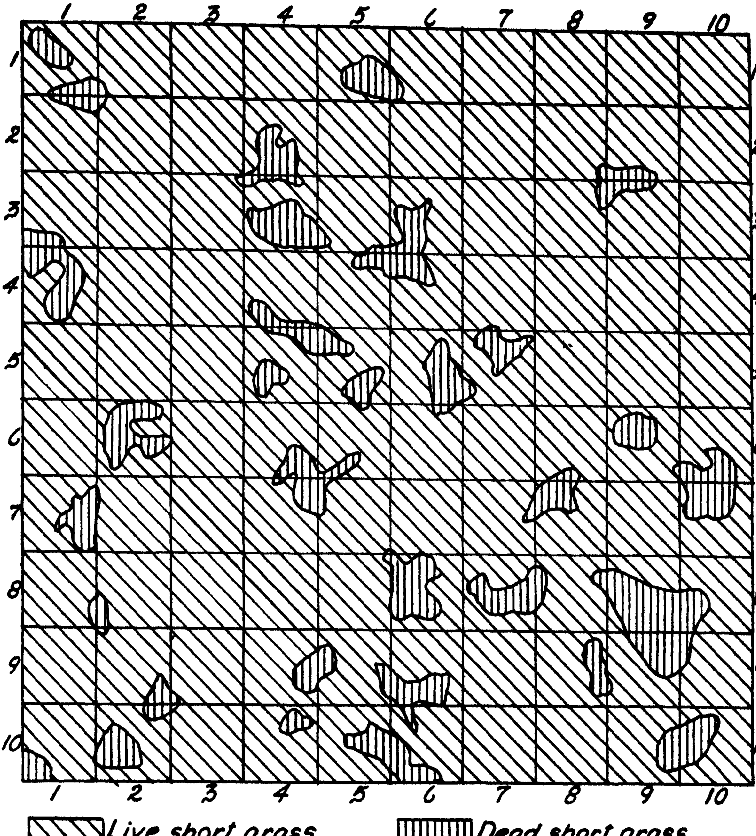

FIG. 7.—Meter quadrat No. 16 on a lawn lightly watered and clipped 1¼ inches high in 1934, showing that 11.0% of the short-grass plants were dead at the end of the drought.

SUGGESTIONS FOR PROMOTING RECOVERY

The results thus far obtained from these quadrat studies are to be used also as a basis for determining the rate and duration of recovery in the future. It is proposed to make repeated charts of the growth until recovery is completed.

Although much of the short grass in the vicinity of Hays, Kans., is shown to be dead, the remaining live plants are rather uniformly distributed and may be expected to spread rapidly under normal conditions if protected from severe damage by livestock. The vigorous growth of stolons produced during the favorable growing period of 59 days prevailing in the fall of 1934 and the recovery made under water-

ing treatments indicate that the original stands may become re-established in a relatively short time.

Transplanting experiments at this station show that 4-inch cubes of buffalo grass sod spaced 1 foot apart on cultivated land will spread to cover the intervening spaces in one season of average rainfall, according to Savage (9, 10). The live plants in the drought-stricken

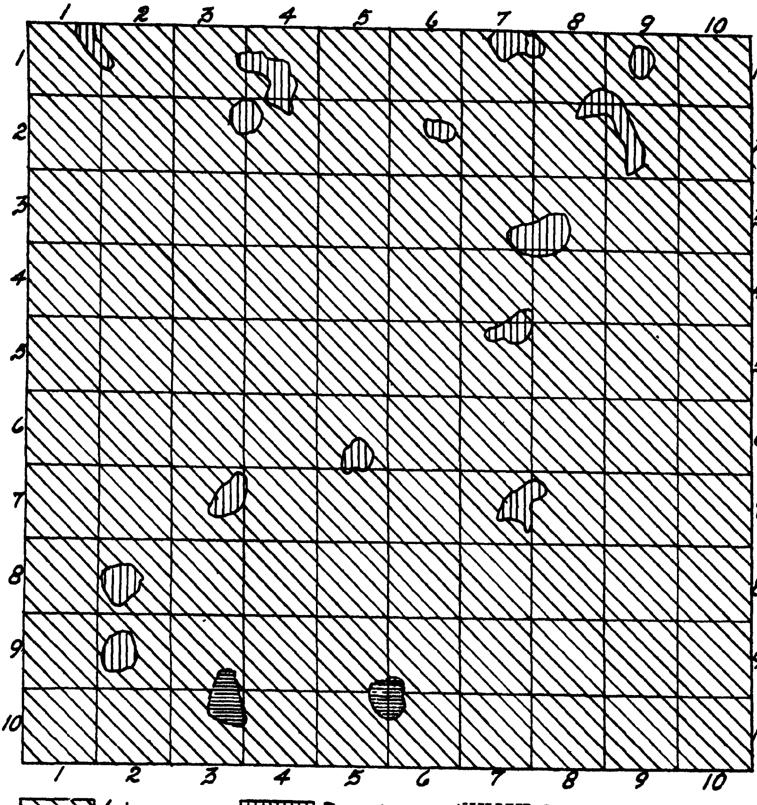

FIG. 8.—Meter quadrat No. 18 on a lawn heavily watered and clipped 1 ¼ inches high in 1934, showing that 2.9% of the short-grass plants were dead at the end of the drought.

areas are generally closer than 1 foot apart and, with their roots undisturbed by transplanting, should spread fast under favorable conditions.

Moderate clipping to eliminate the shading effect of taller grasses and weeds has encouraged the spread of buffalo grass in resodded areas at this station. The spread was materially retarded when the areas were neither clipped nor grazed. Considering the detrimental effects of extreme overgrazing, and of not grazing or cutting, it seems advisable to suggest that a system of deferred, moderate grazing would hasten recovery from drought. Keeping the livestock off the

pastures until about June 1 will encourage the development and rooting of stolons and protect them from early damage by tramping. Thereafter, moderate grazing may keep palatable weeds under control, admit sunlight essential to the spread of short grasses, and shorten the period of recovery. It would be desirable to mow the pastures at intervals to control tall, unpalatable plants, especially during the period when grazing is deferred. Recovery would no doubt be hastened still more by excluding the livestock from the pastures until the spring of 1936, and by mowing often enough to keep the taller growth under control during the season of 1935.

SUMMARY AND CONCLUSIONS

Buffalo grass and blue grama grass are generally considered to be highly resistant to the effects of heat and drought, but in the vicinity of Hays, Kans., many plants of these grasses appear to have been injured beyond recovery by the record-breaking heat and drought of 1933-34.

According to local weather records this was the hottest and driest biennium since 1894-95. A nearly continuous and disastrous drought prevailed in this locality from October 21, 1932, to August 30, 1934.

The charting of live and dead plants in the fall of 1934 was done on typical short-grass pastures and lawns on the Fort Hays (Kansas) Branch Experiment Station. These pastures and lawns assumed a bright green color in the late summer and fall of 1934 as a result of 4.05 inches of precipitation accompanied by marked reductions in previous extremes of temperature and evaporation. Plants which did not renew their growth under these favorable natural conditions were properly assumed to be dead since a representative number of them which were transferred to the greenhouse failed to revive and since the live plants grew vigorously both in the field and in the greenhouse.

A pantograph was used to chart the basal cover of live short grass, dead short grass, other turf-forming vegetation, and bare ground on 54 meter quadrats, 12 of which were located on a closely grazed and severely tramped area, 6 on a moderately grazed area, 16 on dry land lawns clipped at various heights, 10 on lightly watered lawns, and 10 on heavily watered lawns.

The average percentage of short grasses killed by the heat and drought of 1933-34 was 74.8 on closely grazed and severely tramped areas, 64.6 on moderately grazed areas, and 44.4 on unwatered lawns. Repeated applications of water to lawns in 1934 were decidedly beneficial in overcoming the effect of the drought of 1933 and counteracting similar conditions in 1934. Only 14.5% of the short grasses failed to survive on the lightly watered lawns and only 5.1% on the heavily watered lawns.

The average basal cover of short grass on all plats before the drought was 99% as determined from measurements of the live and dead growth after the drought. The heat and drought reduced this cover to an average of 25.2% on the closely grazed areas, 35.4% on the moderately grazed areas, and 54.9% on unwatered lawns. Light watering in 1934 resulted in an average basal cover of 86.0%; heavy watering, 93.9%.

There was a direct and positive correlation between closeness of clipping for 1 year and survival from drought. A similar positive correlation occurred between closeness of clipping and recovery due to watering.

Climatic conditions were directly responsible for the injury on all areas, although close grazing and tramping contributed to the mortality of many plants.

Results obtained from soil-moisture samples indicated that water was not applied to any of the lawn plats in excess of the needs of the grass.

Although much of the short grass in local pastures is dead, the surviving plants are rather uniformly distributed and may be expected to recover rapidly under normal conditions if protected from severe damage by livestock.

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BOOK REVIEW

THE HOP INDUSTRY

By Herbert H. Parker. London: P. S. King & Son, Ltd. 327 pages, illus. 1934. 15 shillings, net. Import duty approx. 45 cents per copy.

THIS book is based on a recent survey on the hop industry in Great Britain, undertaken as a Ph.D. thesis subject and later published in book form under subsidy from the University of London. It deals chiefly with the history, development, and present status of the industry in the British Isles, yet merits the attention of American hop growers, agronomists, and economists, especially on the Pacific Coast where England now looks as a rule for the major portion of her foreign supplies.

The first section provides an historical background of English hop culture and a review of the literature from the introduction of hops in 1524 down to the opening of the present century. The treatment is that of the evolution of the technic of production during this period. The second section deals with present-day problems of production, and contains excerpts and citations to recent research literature in England in the fields of soil fertilization, training, drying, breeding, production costs, marketing, and diseases and pests. Chapter 4 of this section is a review of the status of the industry in the principal hop-producing countries of the world, and of the position of England in relation to continental and American trade.

Section 3 is an analysis of the various attempts which have been made in England to market hops on a collective basis and is of interest to American economists and producers. An appendix contains much statistical data under the headings historical notes, cost of production at different periods, acreage, prices, and customs duties in different countries. The work is concluded with an extensive bibliography of the field covered. (G. W. H.)

AGRONOMIC AFFAIRS

MEETING OF SOUTHERN AGRONOMISTS

THE following program has been arranged for the summer meeting of southern agronomists to be held in Virginia August 7 to 10, inclusive.

WEDNESDAY, AUGUST 7

Leaving Suffolk at eight o'clock in the morning, the group will visit the peanut and cotton station at Holland, Virginia, until 10:30; then proceed to the Truck Experiment Station near Norfolk and look over the vegetable experiments until 2:30 p.m. Thence to the forage crop experiment station near Williamsburg.

THURSDAY, AUGUST 8

Morning

Enroute to and visiting the sun-cured tobacco experiment station at Bowling Green.

Afternoon

Enroute to and visiting the general crop experiment station near Staunton.

FRIDAY, AUGUST 9

Morning

Enroute to and visiting the bright tobacco experiment station at Chatham.

Afternoon

Enroute to and visiting central experiment station at Blacksburg.

SATURDAY, AUGUST 10

Enroute to and visiting the pasture and grazing experiment station at Glade Spring.

Historic, scenic, and other points of interest along the tour include the world's largest peanut processing plants at Suffolk, Hampton Roads, restored Colonial Williamsburg, Jamestown, Yorktown, tobacco houses in Richmond, the City of Richmond, the Valley of Virginia, the University of Virginia, Natural Bridge, Appomattox, Virginia Polytechnic Institute, Mountain Lake, and Fort Chiswell on the historic Boone trail.

The tour will be preceded on Monday and Tuesday, August 5 and 6, by a meeting of the Tobacco Research Committee in Suffolk.

ANNUAL MEETING OF THE SOCIETY

THE twenty-eighth annual meeting of the Society will be held in the Stevens Hotel in Chicago on December 5 and 6, with the American Soil Survey Association beginning its sessions on December 3. These dates coincide with those for the International Livestock Show and the National Hay and Grain Show. Following the usual practice, the Society will meet as a whole in a half-day general session with special programs arranged by the Soils and Crops Sections occupying the remaining time.

PROGRAM OF THE CROPS SECTION AT CHICAGO

PROFESSOR R. D. Lewis, Chairman of the Crops Section of the Society, announces the first call for papers to be presented at the annual meeting of the Society in Chicago next December. A round table session on "Policies and Problems in the Release and Distribution of Corn Hybrids" is being arranged. Round table or panel discussion groups have been suggested for other topics. In view of the agronomic interest in forage crops, papers are suggested for such topics as Forage Crops in Relation to Soil Conservation, Breeding Hay and Pasture Plants, Pasturing of Alfalfa, Composition of Forage Crops in Relation to Animal Nutrition and Diseases, Cold and Drouth Resistance, Root Systems of Farm Crops, and Methods of Obtaining Seedings. Advances in the knowledge of chemicals in weed control may well be reported. Contributions on improved methodology ("new tricks") in agronomic research and education are especially desired.

The title, author, and time required for presentation of the paper should be sent at an early date to Professor Lewis, Department of Agronomy, Ohio State University, Columbus, Ohio. Since the program is to be completely formulated by October 15, titles should be submitted prior to October 1.

JOURNAL
OF THE
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VOL. 27 AUGUST, 1935 No. 8

A COMPARISON OF GLASS AND QUINHYDRONE ELECTRODES FOR DETERMINING THE pH OF SOME IOWA SOILS: III. THE CHANGE IN pH OF THE SOIL-WATER MIXTURE WITH TIME[1]

HAROLD L. DEAN AND R. H. WALKER[2]

IN previous investigations (4, 5),[3] experiments were conducted to determine the suitability of different types of glass electrodes, and to study the variability of the results obtained with glass and quinhydrone electrodes in determining the pH of soils. The study on the suitability of different types of glass electrodes showed that similar results were obtained with each of the four types employed. The modified bulb, silver-silver chloride type, however, was found most practicable for routine determinations. When the determination was made by either the glass or quinhydrone electrode, the variability in the pH of 25 replicate samples of different soils was comparatively small and presumably of little consequence. The "QH" and "QH electrode" errors were found to be only slight for the soils studied and it was concluded that with these soils the quinhydrone electrode method would give fairly reliable results when compared with those obtained with the glass electrode. The potentials of the glass and quinhydrone electrodes were found to change somewhat during the pH determination, and it was concluded that it is desirable to check the glass and quinhydrone electrodes against a known buffer solution at frequent intervals during their use.

In these earlier experiments it was also observed that the potential difference of the soil suspensions, when determined by either the glass or quinhydrone electrodes, changed somewhat with time. Although the potentials of the electrodes themselves changed slightly during the 20 minutes they were immersed in the soil suspensions, when checked against a standard buffer solution before and after immersion, this change appeared to be large enough to account for only a very small portion of the drift observed in the pH of the suspensions.

[1]Journal Paper No. J 253 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 229. Received for publication March 23, 1935.

[2]Research Fellow and Research Associate Professor of Soils, respectively. The authors are indebted to Dr. P. E. Brown for the suggestions and criticisms offered in the course of this work and in the preparation of the manuscript.

[3]Figures in parenthesis refer to "Literature Cited," p. 595.

Biilman and Jensen (2), Hissink (6), Baver (1), Clark and Collins (3), Naftel (7), and others have observed a similar drift in potentials when using the quinhydrone electrode, but in most cases this drift has been attributed to the reaction of the quinhydrone with the soil constituents. This, however, would not explain the apparent drift, though it was small, observed when using the glass electrode. It seemed desirable, therefore, to determine whether there was an actual change in the pH of the soil-water mixture during the period it was under observation. The results of this study are reported in this paper.

REACTION STUDIES ON SOIL SUPERNATANT LIQUIDS

In this study five different soils were used, *viz.*, Tama silt loam, Shelby loam, Carrington loam, Grundy silt loam, and Marshall silt loam. The soils were air-dried and passed through a 20-mesh sieve. Thirty-gram samples of each soil were placed into 150-cc extraction flasks and 75 cc of CO_2-free distilled water were added to each sample. The soil-water mixture was then shaken vigorously for 1 minute and allowed to stand until the pH determinations were made. At the end of ¼, ½, 1, 3, 6, 12, and 24 hours the pH was determined on quadruplicate samples. To make the determinations in the first experiment, the supernatant liquid was poured into a specially constructed U-shaped tube, the glass electrode was then immersed in the liquid and the potential difference was measured. The methods used in making the measurements are fully described in the first paper of this series (4). After the pH determination was made with the glass electrode, quinhydrone was added to the liquid, a platinum electrode was connected with the apparatus, and the pH was again determined.

In this manner determinations of pH were made by the glass and quinhydrone electrode methods on soil samples that had been in contact with water for various periods of time.

The results of this study are shown in Table 1. In order to determine the significance of these data, a statistical analysis of variance was made as described by Snedecor (8). The results of the analysis are presented in Table 2.

It may be noted from the statistical data that the difference between means of quadruplicate samples of the different soils was not significant. This indicates that the variations in the pH of the four replicate samples of soil, when the determinations were made with the glass or quinhydrone electrode, at any one time were not statistically significant. As may be noted in Table 1, the largest difference between samples at any one period with Tama silt loam was small, being only 0.06 of a pH with the glass electrode and 0.13 of a pH with the quinhydrone electrode. Similar differences occurred with other soils. These results confirm those previously reported (5).

The analysis of variance shows also that the differences between means of time for each soil are highly significant. This implies that the pH values determined at various intervals of time change, and that these changes are large in some cases and statistically signifi-

TABLE 1.—*The pH of the supernatant liquid of quadruplicate samples of soil at various periods of time after mixing the soil and water, the determinations being made with glass and quinhydrone electrodes.*

Sample No.	Time in hours															
	0		¼		½		1		3		6		12		24	
	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.
Tama Silt Loam																
1	5.03	5.09	5.03	5.13	5.04	5.13	5.01	5.11	4.99	5.09	4.98	5.03	5.18	5.20	5.26	5.31
2	5.08	5.13	5.04	5.26	5.04	5.13	5.03	5.08	5.01	5.08	5.04	5.08	5.18	5.21	5.25	5.33
3	5.04	5.09	5.06	5.16	5.04	5.18	5.04	5.11	4.99	5.04	5.03	5.11	5.16	5.20	5.21	5.25
4	5.06	5.09	5.06	5.16	5.03	5.11	5.03	5.08	5.01	5.08	5.01	5.04	5.16	5.21	5.26	5.26
Mean	5.05	5.10	5.05	5.18	5.04	5.14	5.03	5.10	5.01	5.07	5.02	5.07	5.17	5.21	5.24	5.29
Shelby Loam																
1	5.70	5.97	5.84	6.08	5.84	6.04	5.82	5.97	5.87	5.96	5.89	5.94	6.06	6.18	6.14	6.26
2	5.74	6.03	5.82	6.09	5.86	6.04	5.84	5.97	5.79	5.99	5.92	5.99	5.89	6.11	6.13	6.28
3	5.74	6.06	5.81	6.08	5.86	5.99	5.84	5.96	5.87	5.99	5.94	5.97	5.84	5.97	6.13	6.23
4	5.75	6.01	5.86	6.06	5.84	6.01	5.86	5.99	5.87	6.01	5.91	6.01	5.87	6.09	6.11	6.19
Mean	5.73	6.02	5.83	6.08	5.85	6.02	5.84	5.96	5.86	5.99	5.92	5.98	5.92	6.09	6.13	6.24
Carrington Loam																
1	5.21	5.28	5.18	5.31	5.16	5.26	5.20	5.30	5.23	5.23	5.18	5.23	5.28	5.38	5.70	5.86
2	5.26	5.40	5.16	5.28	5.16	5.28	5.18	5.25	5.23	5.21	5.23	5.25	5.25	5.37	5.67	5.82
3	5.18	5.31	5.18	5.26	5.21	5.28	5.16	5.25	5.20	5.21	5.21	5.23	5.21	5.33	5.75	5.87
4	5.20	5.30	5.20	5.28	5.16	5.26	5.18	5.28	5.23	5.23	5.20	5.25	5.25	5.31	5.62	5.79
Mean	5.21	5.32	5.18	5.28	5.17	5.27	5.18	5.27	5.22	5.21	5.21	5.24	5.23	5.35	5.69	5.84
Grundy Silt Loam																
1	5.25	5.37	5.40	5.48	5.33	5.43	5.38	5.47	5.40	5.48	5.45	5.57	5.57	5.64	5.62	5.72
2	5.16	5.40	5.37	5.48	5.33	5.47	5.37	5.43	5.33	5.45	5.37	5.48	5.50	5.62	5.64	5.74
3	5.26	5.40	5.35	5.47	5.31	5.47	5.35	5.43	5.35	5.42	5.40	5.47	5.55	5.64	5.60	5.72
4	5.20	5.38	5.40	5.50	5.33	5.48	5.35	5.42	5.35	5.47	5.42	5.53	5.57	5.60	5.60	5.69
Mean	5.22	5.39	5.38	5.48	5.33	5.46	5.36	5.44	5.36	5.46	5.41	5.51	5.55	5.63	5.62	5.72
Marshall Silt Loam																
1	7.53	7.07	7.58	7.07	7.38	7.07	7.53	6.85	7.53	7.11	7.48	6.90	7.33	7.12	6.92	7.16
2	7.48	7.06	7.55	7.04	7.38	7.09	7.50	6.97	7.53	6.65	7.51	7.14	7.40	7.06	7.04	6.87
3	7.55	7.04	7.40	6.85	7.29	7.04	7.58	6.77	7.43	6.89	7.45	7.02	7.23	7.01	7.18	6.96
4	7.56	7.09	7.53	7.03	7.36	7.09	7.55	6.97	7.55	6.96	7.48	7.09	7.26	7.04	7.18	6.79
Mean	7.53	7.07	7.52	7.00	7.35	7.07	7.54	6.89	7.51	6.90	7.48	7.04	7.31	7.06	7.08	6.94

TABLE 2.—*Analysis of variance of pH values of soil-supernatant liquids of five soils at various periods of time after mixing soil and water.*

Source of variation	Degrees of freedom	Mean square				
		Tama silt loam	Shelby loam	Carrington loam	Grundy silt loam	Marshall silt loam
Total	63	——	——	——	——	——
Between means of samples	3	0.0013	0.001	0.001	0.002	0.011
Between means of time	7	0.0516**	0.073**	0.276**	0.108**	0.06**
Between means of electrodes	1	0.068**	0.434**	0.116**	0.187**	2.797**
Interactions:						
Time—samples	21	0.0006	0.003**	0.0015**	0.0009*	0.007
Time—electrodes	7	0.0014	0.010**	0.0046**	0.002**	0.066**
Samples—electrodes	3	0.0007	0.001	0.0000	0.0007	0.005
Remainder	21	0.0008	0.0005	0.0003	0.0004	0.009

*Significant.
**Highly significant.

cant. It may be noted from the original data of Table 1, however, that only slight changes in pH occurred within the first 6 hours the various soils were in contact with water. The mean pH values changed within the first 6 hours only 0.04 pH in the case of Tama silt loam to only 0.19 pH in the case of Shelby loam when the determination was made with the glass electrode. The extent of this change is more clearly shown in the sums of the pH values obtained from quadruplicate samples as shown in Table 3.

It may be noted that the sums of the pH values obtained at different times with both glass and quinhydrone electrodes for the eight samples of soil varied within the 6-hour period to only a slight extent. Variations within this range are considered to be relatively unimportant for most soil reaction studies. After the 6-hour period, however, the pH of the soil-water mixture changed considerably with all the soils. In the acid soils the pH increased with an increase in time, as shown in the case of Tama silt loam when the mean pH increased 0.22 of a pH within the 6- to 24-hour period when the glass electrode method was used. A similar change occurred with the other acid soils, although the increase in pH within the 6- to 24-hour period for Carrington loam was considerably larger, being 0.48 of a pH using the glass electrode method. The magnitude of this change in pH after the 6-hour period is clearly evident when the sums of the pH values, as determined by both glass and quinhydrone electrodes on the eight soil samples, are considered.

In the basic soil, Marshall silt loam, there was practically no change in pH during the first 6 hours; but from the sixth to the twenty-fourth hours, however, there was a rather large decrease in pH when determined with either electrode.

Inasmuch as the pH of all the soils studied changed only slightly during the first 6 hours of the investigation, it is concluded that the statistically significant change in pH of the soils occurred after the 6-

TABLE 3.—*The sum of the results of pH determinations on quadruplicate samples of five soils at various intervals after mixing soil and water, the determinations being made on the soil-water supernatant liquid with glass and quinhydrone electrodes.*

Kind of electrodes	Time in hours								
	0	¼	½	1	3	6	12	24	Total
				Tama Silt Loam					
Glass	20.21	20.19	20.15	20.11	20.00	20.06	20.68	20.98	162.38
Quinhydrone	20.40	20.71	20.55	20.38	20.29	20.26	20.82	21.15	164.56
Total	40.61	40.90	40.70	40.49	40.29	40.32	41.50	42.13	326.94
				Shelby Loam					
Glass	22.93	23.33	23.40	23.36	23.40	23.66	23.66	24.51	188.25
Quinhydrone	24.07	24.31	24.08	23.89	23.95	23.91	24.35	24.96	193.52
Total	47.00	47.64	47.48	47.25	47.35	47.57	48.01	49.47	381.77
				Carrington Loam					
Glass	20.85	20.72	20.69	20.72	20.89	20.82	20.99	22.74	168.42
Quinhydrone	21.29	21.13	21.08	21.08	20.88	20.96	21.39	23.34	171.15
Total	42.14	41.85	41.77	41.80	41.77	41.78	42.38	46.08	339.57
				Grundy Silt Loam					
Glass	20.87	21.52	21.30	21.45	21.43	21.64	22.19	22.46	172.86
Quinhydrone	21.55	21.93	21.85	21.75	21.82	22.05	22.50	22.87	176.32
Total	42.42	43.45	43.15	43.20	43.25	43.69	44.69	45.33	349.18
				Marshall Silt Loam					
Glass	30.12	30.06	29.41	30.16	30.04	29.92	29.22	28.32	237.25
Quinhydrone	28.26	27.99	28.29	27.56	27.61	28.15	28.23	27.78	223.87
Total	58.38	58.05	57.70	57.72	57.65	58.07	57.45	56.10	461.12

hour period. It is evident, therefore, that for practical purposes, where determinations are to be made within a few minutes after mixing the soil with water, the time factor has no significant influence on the results obtained.

The results of the statistical analysis in Table 2 show also that the difference between the means of electrodes is highly significant. As may be noted from the original data in Table 1, the glass electrode gave consistently lower pH values than the quinhydrone electrode in acid soils. The differences in the mean pH values obtained with the glass and quinhydrone electrodes varied, in the case of the Tama silt loam from 0.04 of a pH to 0.13 of a pH during the 24-hour period, the largest differences during the 24-hour period being from 0.06 to 0.29 pH. Other acid soils gave similar results. This difference between electrodes is more clearly shown when the sums of all the pH values of each soil, when determined with the glass electrode, are compared with the sums of all pH values of each soil when determined with the quinhydrone electrode. For instance, it may be noted from Table 3 that, with the Tama silt loam, the sum of the pH values obtained with the glass electrode was 162.38 in comparison with 164.56 obtained with the quinhydrone electrode. Similar differences in the sum of pH values were obtained with the other acid soils. With the basic Marshall silt loam, the glass electrode

gave consistently higher pH values than the quinhydrone electrode. The sum of the pH values with this soil was 237.25 for the glass electrode and 223.87 for the quinhydrone electrode. These results confirm those previously published (5).

Because of the comparatively small range of variability of the results obtained with either the glass or the quinhydrone electrode, the differences in average results between the two electrodes have proved statistically significant. It is believed, however, that these differences are still within a range wherein differences are relatively unimportant for most soil reaction studies.

The analysis of the data also shows that the interaction between time and samples is significant in three soils. This means that the order of the reaction of different soil samples changed from time to time, or that the magnitude of the differences between samples at different times was larger than in the case of the soils which show a non-significant interaction. It may be observed further that the interaction between time and electrodes is highly significant with all but one soil, the Tama silt loam. This interaction shows that, although there was a significant difference between means of electrodes and that the values obtained were always higher for one electrode on a particular soil, as was pointed out above, the difference between electrodes was not of the same magnitude at different times. The analysis in Table 2 shows further that the interaction between samples and electrodes was not significant in any case, indicating that both electrodes behaved in the same manner on the same samples of soil.

REACTION STUDIES ON SOIL SUSPENSIONS

In this experiment the same general procedure was followed as in the previous one, except that the pH was determined with the electrodes immersed in soil suspensions instead of in the supernatant liquid of the soil-water mixture. At the various designated times the soil-water mixture was shaken vigorously for 15 seconds, the suspension poured into the U-shaped tube, and the hydrogen-ion concentration determined. The results of this study are presented in Table 4. Recognizing the variability within the data of this table, it seemed desirable to analyze the data statistically by the analysis of variance method. The results of this analysis are shown in Table 5.

The data show that the means between samples are not significant except for the Marshall silt loam. This means that the pH of the quadruplicate samples of the Tama, Shelby, Carrington, and Grundy soils did not vary sufficiently to be statistically different. In other words, the quadruplicate results are indicative of homogeneity. In the case of the Marshall silt loam, however, there was some difference in the pH values obtained with quadruplicate samples at various times. The largest range of variation in pH for the quadruplicate samples of this soil was 0.13 pH when the glass electrode was used and 0.12 pH when the quinhydrone electrode was employed. Although this variability was sufficiently large to in-

TABLE 4.—*The pH of the soil suspension of quadruplicate samples of soil at various periods of time after mixing soil and water, the determinations being made with glass and quinhydrone electrodes.*

Sample No.	Time in hours															
	0		¼		½		1		3		6		12		24	
	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.
Tama Silt Loam																
1	4.91	5.03	4.98	5.04	4.94	5.01	4.93	5.06	5.01	5.06	4.93	5.08	4.93	5.09	5.06	5.20
2	4.89	5.01	5.03	5.03	4.96	5.01	4.94	5.04	4.91	4.99	4.96	5.13	4.96	5.13	5.09	5.25
3	4.91	5.01	4.93	5.03	4.93	5.01	4.91	4.99	4.96	5.01	4.98	5.06	4.94	5.11	5.09	5.26
4	4.86	4.99	4.96	5.06	4.91	5.01	4.94	4.99	4.86	5.01	4.99	5.04	4.98	5.11	5.15	5.28
Mean	4.89	5.01	4.97	5.04	4.94	5.01	4.93	5.02	4.93	5.02	4.97	5.08	4.95	5.11	5.10	5.25
Shelby Loam																
1	5.72	5.96	5.70	5.97	5.70	6.03	5.77	5.91	5.74	6.03	5.79	6.03	5.75	6.04	5.89	6.03
2	5.82	5.77	5.74	6.01	5.75	6.01	5.77	5.97	5.81	6.01	5.79	5.96	5.79	6.01	5.86	6.04
3	5.82	5.96	5.75	6.04	5.74	5.96	5.74	5.99	5.77	6.03	5.82	5.89	5.77	5.97	5.89	6.01
4	5.81	5.97	5.81	6.04	5.74	5.96	5.81	5.97	5.79	5.99	5.77	5.96	5.77	6.01	5.94	6.03
Mean	5.79	5.96	5.75	6.02	5.73	5.99	5.77	5.96	5.78	6.02	5.79	5.96	5.77	6.01	5.90	6.03
Carrington Loam																
1	5.21	5.30	5.20	5.30	5.20	5.33	5.21	5.30	5.20	5.26	5.21	5.33	5.30	5.33	5.50	5.55
2	5.18	5.26	5.20	5.31	5.21	5.33	5.20	5.30	5.23	5.28	5.26	5.35	5.28	5.33	5.45	5.59
3	5.23	5.28	5.21	5.30	5.18	5.31	5.16	5.30	5.21	5.37	5.28	5.31	5.28	5.30	5.45	5.57
4	5.20	5.30	5.21	5.30	5.23	5.31	5.20	5.28	5.23	5.33	5.23	5.30	5.28	5.31	5.47	5.55
Mean	5.21	5.29	5.21	5.30	5.21	5.32	5.19	5.30	5.22	5.31	5.25	5.32	5.29	5.32	5.47	5.57
Grundy Silt Loam																
1	5.26	5.31	5.25	5.37	5.30	5.37	5.30	5.35	5.38	5.40	5.26	5.38	5.40	5.43	5.42	5.38
2	5.21	5.33	5.16	5.35	5.31	5.35	5.28	5.33	5.26	5.40	5.28	5.37	5.43	5.40	5.40	5.40
3	5.21	5.33	5.25	5.35	5.28	5.35	5.25	5.33	5.23	5.40	5.28	5.33	5.40	5.40	5.43	5.45
4	5.26	5.31	5.21	5.38	5.30	5.37	5.25	5.35	5.23	5.38	5.23	5.35	5.43	5.38	5.40	5.40
Mean	5.24	5.32	5.22	5.36	5.30	5.36	5.27	5.34	5.28	5.40	5.26	5.36	5.42	5.40	5.41	5.41
Marshall Silt Loam																
1	7.55	7.53	7.50	7.56	7.51	7.55	7.55	7.58	7.51	7.56	7.46	7.50	7.45	7.55	7.41	7.41
2	7.50	7.53	7.53	7.60	7.55	7.60	7.53	7.63	7.50	7.58	7.50	7.53	7.50	7.62	7.41	7.45
3	7.50	7.56	7.58	7.58	7.56	7.56	7.55	7.65	7.50	7.62	7.46	7.51	7.48	7.58	7.41	7.43
4	7.50	7.56	7.63	7.63	7.56	7.62	7.51	7.65	7.48	7.50	7.50	7.55	7.46	7.65	7.43	7.45
Mean	7.51	7.55	7.56	7.59	7.55	7.58	7.54	7.63	7.50	7.57	7.48	7.52	7.47	7.60	7.42	7.44

TABLE 5.—*Analysis of variance of pH values of water suspensions of five soils at various periods of time after mixing soil and water.*

Source of variation	Degrees of freedom	Mean square				
		Tama silt loam	Shelby loam	Carrington loam	Grundy silt loam	Marshall silt loam
Total	63	—	—	—	—	—
Between means of samples	3	0.0003	0.001	0.000	0.001	0.003**
Between means of time	7	0.039**	0.009**	0.066**	0.204**	0.020**
Between means of electrodes	1	0.182**	0.635**	0.121**	0.078**	0.051**
Interaction:						
Time—samples	21	0.0014	0.0014	0.0005	0.0007	0.001
Time—electrodes	7	0.0023*	0.008**	0.0013*	0.006**	0.003**
Samples—electrodes	3	0.0003	0.007**	0.0003	0.001	0.0007
Remainder	21	0.0007	0.001	0.0005	0.0007	0000.6

*Significant.
**Highly significant.

dicate real differences between the different samples of soil, in this case it is believed that they are still within a range wherein the differences are relatively unimportant for most soil reaction studies. Assuming this to be true, the data of this experiment, obtained by determining the pH in soil suspensions, are in agreement with those obtained in the previous experiment where the determinations were made on the supernatant liquid.

It may also be observed that the differences in pH between means of time are highly significant with all soils, meaning that the pH values determined at various intervals of time changed and that the changes were large in some cases and statistically significant. The data in Table 4, however, show that only slight changes in pH occurred during the first 12 hours the soils were in contact with water when the determination was made by either electrode. As may be noted in the case of the Carrington loam, the mean pH of quadruplicate samples varied only 0.10 of a pH during the first 12 hours, and when the sums of the pH values, as shown in Table 6, are compared, it is more clearly shown that the changes in pH during the first 12 hours were small. These changes are considered of doubtful significance in soil reaction studies. Larger changes in pH values, however, occurred after the 12-hour period the soil was in contact with water. As shown with the Carrington loam, the mean pH of quadruplicate samples increased from 5.29 at the twelfth hour to 5.47 at the twenty-fourth hour when determined with the glass electrode. A similar change occurred when the quinhydrone electrode was used, the change being 0.25 pH. This change is emphasized by the sums of the quadruplicate pH values. Hence these data clearly indicate a definite increase in pH after the 12-hour period when either electrode is used. It may be concluded, therefore, that the significant change in pH values of the soil suspensions occurred after the twelfth hour, and that since there is no practical

advantage in allowing soil to remain in contact with water more than 1 or 2 hours in routine determinations, the time factor is of no importance in determining the pH of soils with either of these electrodes.

TABLE 6.—*The sum of the results of pH determinations on quadruplicate samples of five soils at various intervals after mixing soil and water, the determinations being made on soil suspensions with glass and quinhydrone electrodes.*

Kind of electrodes	Time in hours								
	0	¼	½	1	3	6	12	24	Total
				Tama Silt Loam					
Glass........	19.57	19.88	19.74	19.72	19.74	19.86	19.81	20.39	158.71
Quinhydrone.	20.04	20.16	20.04	20.08	20.07	20.31	20.44	20.99	162.13
Total........	39.61	40.04	39.78	39.80	39.81	40.17	40.25	41.38	320.84
				Shelby Loam					
Glass........	23.17	23.00	22.93	23.09	23.11	23.17	23.08	23.58	185.13
Quinhydrone.	23.66	24.06	23.96	23.84	24.06	23.84	24.03	24.11	191.56
Total........	46.83	47.06	46.89	46.93	47.17	47.01	47.11	47.69	376.69
				Carrington Loam					
Glass........	20.82	20.82	20.82	20.77	20.87	20.98	21.14	21.87	168.09
Quinhydrone.	21.14	21.21	21.28	21.18	21.24	21.29	21.27	22.26	170.87
Total........	41.96	42.03	42.10	41.95	42.11	42.27	42.41	44.13	338.96
				Grundy Silt Loam					
Glass........	20.94	20.87	21.19	21.08	21.10	21.05	21.66	21.65	169.54
Quinhydrone.	21.28	21.45	21.44	21.36	21.58	21.43	21.61	21.63	171.78
Total........	42.22	42.32	42.63	42.44	42.68	42.48	43.27	43.28	341.32
				Marshall Silt Loam					
Glass........	30.05	30.24	30.18	30.14	29.99	29.92	29.89	29.66	240.07
Quinhydrone.	30.18	30.37	30.33	30.51	30.26	30.09	30.40	29.74	241.88
Total........	60.23	60.61	60.51	60.65	60.25	60.01	60.29	59.40	481.95

The statistical analysis also shows that the differences between means of electrodes are at least significant for every soil and highly significant in all but the Shelby loam. This indicates that the glass and quinhydrone electrodes did not give the same pH values for the soils studied. It is obvious from the original data that the glass electrode gave consistently lower pH values than the quinhydrone electrode for these soils. This point is clearly shown by the sums of the pH values shown in Table 6. These results agree with those of the previous test except that the glass electrode gave lower results with all the soils in this case, whereas the glass electrode gave higher results for the Marshall silt loam when the determinations were made on the supernatant liquid.

The statistical analysis also shows that the interaction between time and samples is not significant. This indicates that the differences in the pH values of different soil samples were not large at the various times. The interaction between time and electrodes is significant for all soils and highly significant for the Shelby, Grundy,

and Marshall soils. This significant interaction shows that, although there was a significant difference between means of electrodes, and that the pH values obtained were always higher for one electrode on a particular soil, the difference between electrodes was not of the same magnitude at different times. The analysis shows further that the interaction between samples and electrodes was highly significant with only one soil, the Shelby loam. This indicates that the two electrodes did not behave in the same manner on the same samples of this soil. The electrodes did behave similarly, however, with samples of the other four soils.

In general, it may be observed from the data of these two experiments that similar results were obtained when determining the pH in soil suspensions or in supernatant liquids of the soils studied within the first 6 hours, and that somewhat different results were obtained with the two methods after that period.

During the progress of these experiments it was observed that the soil sample in which the pH is being determined may be shaken without appreciably changing the potential. It was observed with the glass electrode, however, that the potential may be changed considerably by merely moving the electrode up and down in the soil suspension. It is believed desirable, therefore, that the glass electrode be raised up and down in the solution only two or three times when the electrode is placed in the soil-water mixture. The electrode should then be left undisturbed until the pH has been determined.

SUMMARY AND CONCLUSIONS

Experiments were conducted to determine the influence on the hydrogen-ion concentration of five Iowa soils of the length of time soil is in contact with water in suspension. Seventy-five cc of distilled water were added to 35 grams of soil and allowed to stand for 0, ¼-, ½-, 1-, 3-, 6-, 12-, and 24-hour intervals, after which hydrogen-ion concentration was determined by the glass and quinhydrone electrodes on soil suspensions and on supernatant liquids. The data were analyzed statistically by the analysis of variance and the following conclusions have been drawn:

1. The variability in the pH of quadruplicate samples of different soils at any time was comparatively small when determinations were made in either the supernatant liquid or the soil suspension.

2. There was very little change in the pH of the supernatant liquids or the soil suspensions during the first 6 and 12 hours, respectively, after preparation. After that time, however, there was a significant increase in the pH of the acid soils and a decrease in the pH of the basic soil. This change in pH is presumably of no practical significance as it does not occur until a rather long time after preparation of the samples for pH determination.

3. The glass electrode method gave consistently lower results than the quinhydrone electrode method in all soils, except in the supernatant liquid of Marshall silt loam where it gave slightly higher results. The differences obtained by the two methods were so small that they are considered of little significance in actual practice.

4. Repeated moving up and down of the glass electrode in the soil-water mixture resulted in lower pH values of the soils studied. It is recommended, therefore, that the electrode be moved up and down only two or three times in the soil-water mixture immediately after immersion and that it then be left undisturbed until the pH determination is made.

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THE MECHANISM OF PHOSPHATE RETENTION BY NATURAL ALUMINO-SILICATE COLLOIDS[1]

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THE problem of supplying plants with phosphorus is of extreme importance and is complicated by the fact that the colloidal fraction of soils has the inherent property of converting soluble phosphates of fertilizers into insoluble forms. Various investigators have done much to clarify the behavior of phosphates in the soil, but there is still a lack of agreement in the interpretation of the results obtained. This lack of agreement appears to arise from the failure to take into account some of the important factors that affect the behavior of phosphates in soils. The principal functional fraction of a soil is made up of interrelated colloidal systems called colloidal ampholytes by Mattson and Pugh (8).[3] Since the surfaces of these systems attract cations and anions with electrostatic forces which vary in magnitude according to the environmental conditions of temperature, concentration, and reaction, it becomes obvious that the interpretation of any specific experimental data requires the careful consideration of many factors.

The vast literature which relates to phosphate behavior cannot be reviewed here. It is sufficient to refer only to those investigations which served as stepping stones to the plan of this study.

Roszman (13), in 1927, suggested the possibility that the clay complex might be partially responsible for the retention of phosphates. The author's investigations (14, 15, 16) indicated that the retention of phosphates by soils was more complicated than could be explained with data from heterogeneous soil colloidal systems. It was necessary to have information from simpler systems in order better to understand the chemistry of the phosphates and the physico-chemical constitution of the soil colloids before the concept of the present study could be developed. The work of Gaarder (7) and of Mattson (9) were especially valuable in this connection.

Gaarder has clearly set forth the behavior of the phosphate ion in the presence of free ions of iron, aluminum, calcium, magnesium, and sodium. Mattson contends that soil colloids are principally amphoteric precipitates which have surface valences that vary in their attractive forces for different cations and anions, and that the electrostatic forces and the sign of the valences depend upon the pH

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[3]Reference by numbers in parenthesis is to "Literature Cited," p. 615.

of the medium. In 1931, Bradfield (2) suggested the probability that phosphates are in part retained on the surfaces of the alumino-silicates in the soils and may be replaced by other anions. Recently, Demolon (6), Ravikovitch (12), and Pugh (11) have published papers dealing with the ionic exchange of phosphates.

The present investigation was started in 1932 when the concept of anion exchange had received almost no experimental verification. This paper reports only the most significant data obtained in an investigation of the mechanism of phosphate retention by relatively simple, alumino-silicate colloidal systems of varying compositions at different pH values in the presence of calcium or sodium cations. An attempt is made to interpret the results in order to give a clearer understanding of the mechanism of phosphate retention by soils. Special attention is given to the verification of the data with growing plants on normal soils.

PHOSPHATE RETENTION BY ALUMINO-SILICATE COLLOIDS OF LOW AND HIGH IRON CONTENT

PREPARATION OF MATERIAL

The alumino-silicate colloid used was prepared from a low-iron (3.1% Fe_2O_3) bentonite by agitating the bentonite in water in a barrel churn for 8 hours and allowing the suspension to settle for about 15 hours. The material remaining in suspension was then syphoned off and run into a Sharples supercentrifuge. The suspension passing through the centrifuge at 18,000 r. p. m was concentrated by removing water in the process of electrodialysis. The silica-sesquioxide ratio of the electrodialized colloid was 4.54. Over 68% of the colloidal particles were less than 125 millimicrons in diameter. The pH and conductivity curves for the colloid when titrated with 0.042 N $Ca(OH)_2$ are given in Fig. 1. These show that the critical deflection points in both pH and conductivity occur at about 100 M. E. of the cation per 100 grams of the colloid.

The general scheme of experimental procedure is given diagrammatically in Fig. 2. The colloid designated as "high in iron" was enriched with iron by the addition of $FeCl_3$ to the electrodialized bentonite colloid. This "ferriferated" alumino-silicate was then electrodialized to remove the mobile ions of Cl and Fe. During the initial period (5 days) of this dialysis, the pH of the colloid was maintained near 4.5 by frequent additions of NaOH. At this reaction the unsorbed iron was carried away from the colloid to the cathode membrane of the cell where it could be removed. The added Na ions acted as conductors of the electric current and thus facilitated the removal of the Cl ions. In order to make the newly formed colloid uniform throughout in respect to oxidation and reduction, a 3% solution of H_2O_2 was added. The colloid was then electrodialized without the addition of more NaOH until it was free of all mobile ions. This colloid then contained 6.3% Fe_2O_3. Since the iron retained was sorbed on the surfaces of the alumino-silicate colloid, it is valid to assume that the "ferriferated" alumino-silicate colloid would exhibit characteristics of a soil colloid rich in iron.

The individual colloidal systems on which all determinations were made consisted of 2 grams of the colloid in a final volume of 250 cc. The phosphorus was added in the form of H_3PO_4 to each series in four concentrations consisting of 3.2, 6.5, 12.9, and 25.8 millimols of H_3PO_4 per 100 grams of the colloid. The hy-

droxides of calcium and sodium were added in such progressively increasing amounts to the four series indicated in Fig. 1 that the final pH values would be over a wide range.

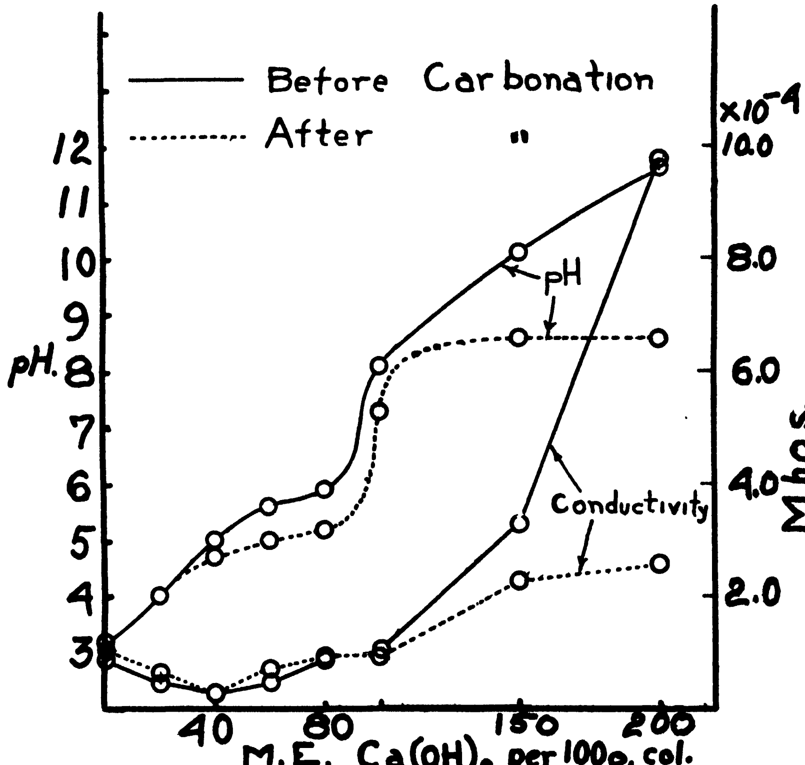

FIG. 1.—The relation of the pH and conductivity of the electrodialized alumino-silicate (bentonite) colloid to the concentration of $Ca(OH)_2$ before carbonation and after carbonation when equilibrated to the CO_2 content of ordinary air.

DETERMINATIONS AND METHODS

The data obtained from these systems consisted of determinations for the pH value, the electrical conductivity, and the phosphorus remaining in solution. (The difference between the amounts of phosphorus added and that remaining in solution was taken to represent the amount of phosphorus retained by the colloid.) These determinations were made on each individual system before treatment with CO_2 and also after aspirating with CO_2 and equilibrating them with air according to the method of Bradfield and Allison (4). In order to determine when equilibrium was approached in the systems, all of these determinations were made at the end of 1, 5, and 15 days after the set-up in the case of the low-iron colloids. It was found that equilibrium was established at the end of 24 hours in the acid ranges, but at the most alkaline reactions, pH 9.0 to 11.0, there was still some shift even at the end of 15 days.

The pH determinations were made by the glass electrode method (10) and the phosphorus was determined by an adaptation of the colorimetric method of Benedict and Theis (1). The clear extract for the phosphorus determination was obtained by centrifuging the colloid suspension. The systems containing Na were centrifuged until the bulk of the colloid settled out of suspension; then an aliquot sample of the suspension, which was nearly free of suspended colloid,

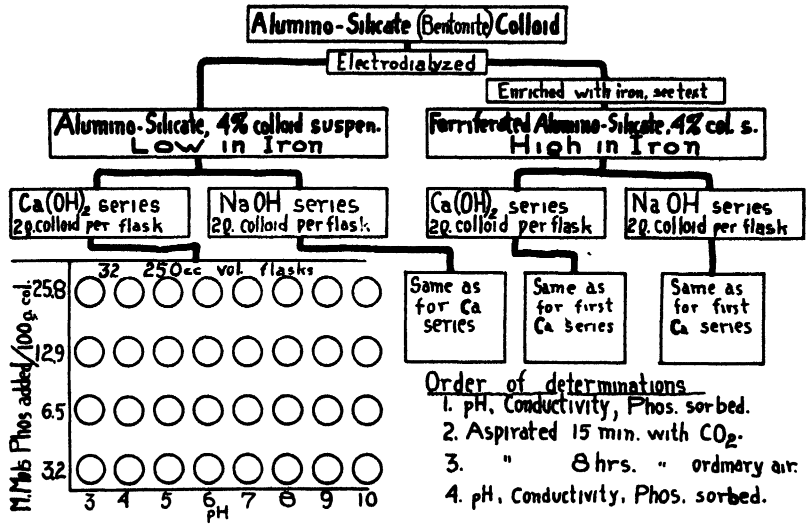

FIG. 2.—General scheme of experimental procedure.

was transferred to a second centrifuge tube where sufficient NaCl was added to cause the remaining suspended colloid to flocculate. When this was centrifuged a clear extract was obtained. A check was made to estimate the error introduced by this procedure of flocculation by comparing it with a similar system where the NaCl was not added and where the clear extract was obtained by dialysis. No measurable error was noted.

RESULTS OBTAINED

Table 1 contains the data on the amount of phosphate retained by the low-iron content colloid. Since a field soil contains abundant CO_2 that will convert any excess hydroxides into carbonates, the most practical phases of the data in Table 1 are those obtained after the systems were carbonated and equilibrated to the CO_2 content of ordinary air. These data have been graphed in Fig. 3. It will be noted that the two families of curves in Fig. 3 have certain characteristics that are functions of the kind of cation present; for example, all the phosphate is retained at the high pH values in the Ca-series, while little or no phosphate is retained at the high pH values in the Na-series. (No significance can be attached to the data obtained at pH values above 8.8 in the presence of Na ions because it was found that in these instances the colorimetric method for determining soluble phosphorus gave abnormally high values. It appears that some

TABLE 1.—*Phosphate retained from solutions varying in concentrations of H_3PO_4 by electrodialized, low-iron content, alumino-silicate colloidal systems that differ in pH values by the addition of $Ca(OH)_2$ or NaOH; data obtained before and after equilibration with CO_2 and reported on the basis of 100 grams of the colloid.*

M. Mols H_3PO_4 added	Calcium series							Sodium series						
	M.E. Ca added	Before carbonation			After carbonation			M.E. Na added	Before carbonation			After carbonation		
		pH	Cond. 30° C X10^{-5}	PO_4 retained M. Mols	pH	Cond. 30° C X10^{-5}	PO_4 retained M. Mols		pH	Cond. 30° C X10^{-5}	PO_4 retained M. Mols	pH	Cond. 30° C X10^{-5}	PO_4 retained M. Mols
3.2	0.0	3.2	22.5	Nil	3.3	11.4	Nil	0.0	3.3	17.7	0.2	3.3	14.9	0.5
	25.2	3.8	7.2	1.2	3.8	5.2	1.2	13.3	4.3	5.5	0.4	4.0	6.1	1.1
	50.4	4.9	2.0	3.1	5.2	1.6	3.1	26.6	5.2	4.1	1.6	5.0	4.3	1.6
	69.4	5.6	2.0	3.2	5.6	1.5	3.2	47.9	6.3	4.4	3.2	6.1	4.1	3.2
	84.0	6.0	2.2	3.1	6.4	2.8	3.1	69.1	6.6	4.5	3.2	6.4	4.8	3.1
	92.5	6.8	3.8	2.8	7.0	3.6	2.5	90.5	7.2	8.3	1.3	7.1	9.9	1.7
	111.5	7.9	8.3	1.7	8.0	11.7	2.2	111.7	9.4	18.1	—0.5	8.0	23.5	0.5
	157.5	10.6	19.1	3.2	8.9	33.0	3.1	159.5	11.1	67.7	—0.9	8.9	55.4	Nil
6.5	0.0	3.2	18.9	Nil	3.2	19.8	Nil	0.0	3.2	19.7	0.4	3.7	21.8	0.9
	29.4	3.8	9.9	2.2	3.8	8.5	2.4	15.9	4.2	8.3	0.9	4.4	9.4	2.3
	54.4	5.0	2.7	5.1	5.1	2.7	5.4	31.9	5.2	7.0	2.0	5.4	6.9	3.1
	73.6	5.7	2.1	6.3	5.6	1.7	6.2	53.2	6.1	6.1	4.5	6.3	6.4	5.0
	88.2	6.4	2.7	6.3	6.2	3.4	5.8	74.5	6.6	6.9	5.1	6.6	8.1	5.0
	96.6	7.0	3.9	6.0	7.3	4.1	5.2	95.9	7.6	11.8	1.4	7.5	29.7	Lost
	117.8	8.2	8.5	4.6	8.1	12.4	5.3	117.0	9.5	22.2	—0.9	8.2	31.8	—0.6
	168.0	10.7	17.6	6.5	8.7	33.4	6.5	170.0	11.3	70.4	—1.3	8.9	88.7	—1.0
12.9	0.0	3.0	31.6	1.0	2.9	31.2	2.5	0.0	3.1	32.8	1.0	3.5	34.8	1.4
	44.2	3.9	11.8	6.0	3.7	10.0	5.8	21.2	3.8	14.5	2.2	4.0	14.5	2.9
	69.4	4.8	5.0	10.4	4.7	4.1	10.2	39.9	4.9	11.0	3.7	5.0	13.1	3.9
	86.2	5.6	3.8	11.9	5.4	3.5	10.2	58.8	5.8	10.0	6.0	5.6	12.7	5.3
	98.7	6.3	6.0	10.5	6.5	4.8	8.5	74.5	6.3	8.9	6.7	6.6	13.3	9.6
	111.2	7.0	7.9	9.5	7.4	9.1	9.3	95.9	6.9	11.1	6.5	7.3	14.4	7.7
	134.2	8.0	10.2	9.9	8.1	Lost	10.2	127.6	8.5	30.8	—2.0	8.2	41.7	—0.2
	195.2	10.8	19.4	12.9	8.7	29.1	12.9	191.3	11.2	103.0	—2.8	8.7	74.2	Nil
25.8	0.0	2.9	61.0	3.7	2.8	60.5	3.1	0.0	2.9	66.0	1.0	3.0	64.2	1.2
	65.1	3.8	20.2	9.4	3.8	17.0	12.5	37.2	3.7	25.0	0.3	4.1	25.2	1.0
	94.5	4.9	11.8	16.3	4.8	10.5	16.6	69.1	5.2	18.6	7.7	5.5	21.8	5.1
	109.2	6.0	11.5	16.2	6.1	13.6	15.8	95.9	6.2	17.6	9.4	6.5	18.1	10.0
	126.0	6.8	13.0	19.0	7.0	14.6	18.2	111.7	6.9	23.9	9.7	7.1	31.9	7.7
	140.9	7.4	12.9	19.3	7.7	15.8	20.2	127.6	7.5	36.0	2.6	7.7	42.5	3.5
	164.0	8.0	13.6	21.9	8.0	13.1	23.4	165.0	9.6	62.2	—3.8	8.0	74.2	2.5
	230.0	10.4	12.5	25.8	8.3	23.7	25.8	234.0	11.3	127.7	—0.3	8.7	127.7	2.5

types of soluble silicates form a blue color with the test reagents similar to that formed with the phosphate.)

A close study of Fig. 3 shows that the alumino-silicate colloid is responsible for the phosphate retention at the slightly acid pH values. Except where only 3.2 millimols of H_3PO_4 were added, more phos-

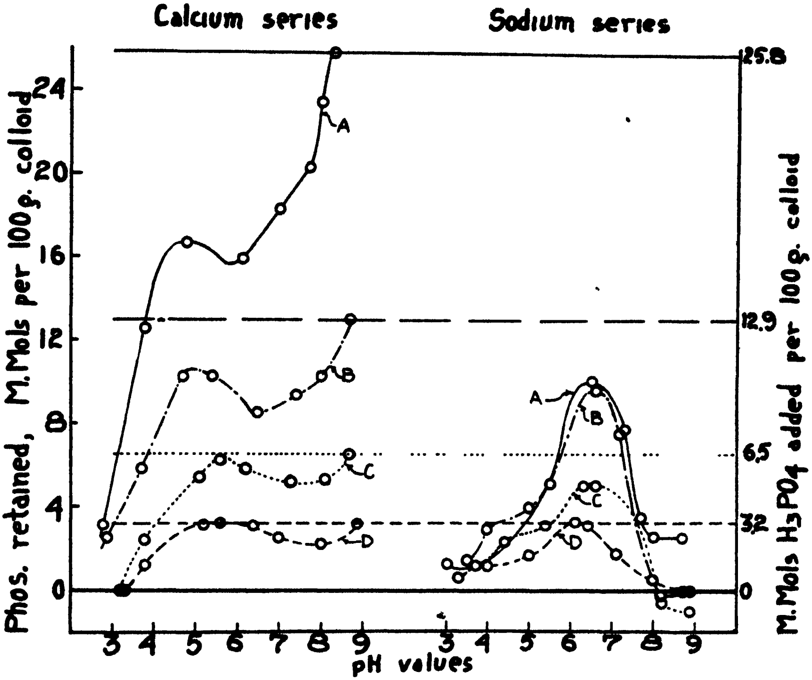

FIG. 3.—Graphic presentation of a portion of the data from Table 1, showing the relation between the phosphate retained by the *low-iron content* alumino-silicate colloids and the pH values in the presence of varying amounts of calcium or sodium and after the systems were equilibrated to the CO_2 content or ordinary air.

A, Phosphorus retained when 25.8 millimols of H_3PO_4 were added.
B, Phosphorus retained when 12.9 millimols of H_3PO_4 were added.
C, Phosphorus retained when 6.5 millimols of H_3PO_4 were added.
D, Phosphorus retained when 3.2 millimols of H_3PO_4 were added.

phate was retained by the alumino-silicate colloid at the maximum point in the acid range where Ca instead of Na was the cation present. It will later be shown that this is a significant fact. The curves also show that insoluble calcium phosphate was formed in the Ca-series at the pH values above those at which the base exchange complex was saturated. It is obvious that insoluble calcium phosphate was formed from the free Ca ions not sorbed by the colloid in the presence of free $CaCO_3$. Proof of this is found in the Na-series where the phosphate in solution increased as the pH values increased. Sodium phosphates are soluble and calcium phosphates are insoluble at high pH values (7). Since there was not any free iron in these colloid systems the phosphate was not retained at the very acid pH values.

It is important to note that the amount of soluble phosphate was reduced by changing the reaction from very acid to only slightly acid. When the amount of soluble phosphate added was small (3.2 millimols of H_3PO_4), the retention was 100%. When the amount of soluble phosphate added was great, the retention was not complete.

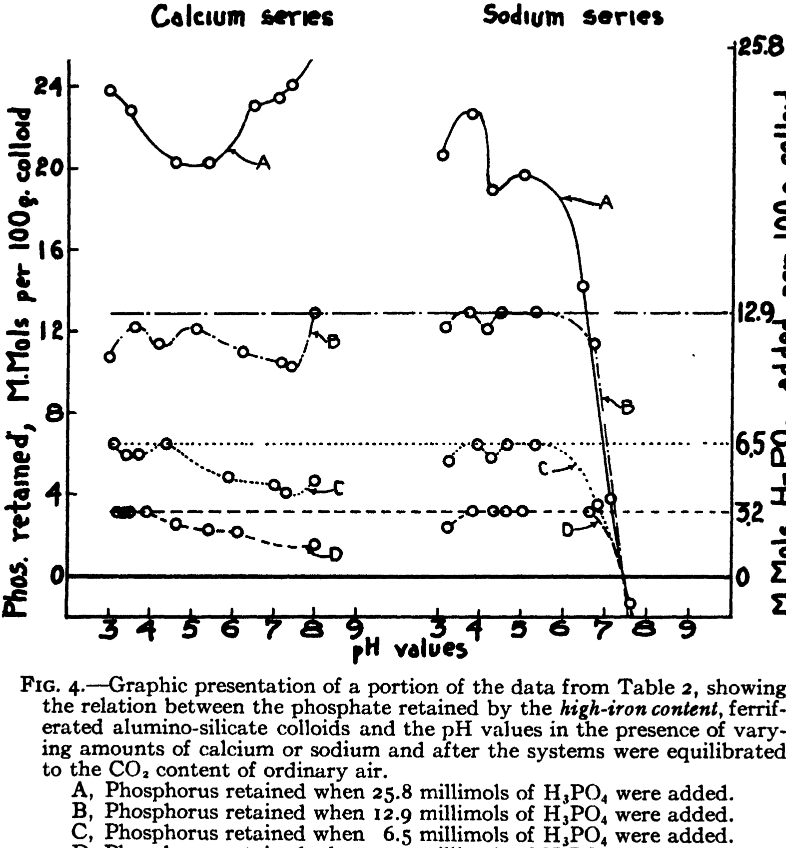

FIG. 4.—Graphic presentation of a portion of the data from Table 2, showing the relation between the phosphate retained by the *high-iron content*, ferriferated alumino-silicate colloids and the pH values in the presence of varying amounts of calcium or sodium and after the systems were equilibrated to the CO_2 content of ordinary air.

A, Phosphorus retained when 25.8 millimols of H_3PO_4 were added.
B, Phosphorus retained when 12.9 millimols of H_3PO_4 were added.
C, Phosphorus retained when 6.5 millimols of H_3PO_4 were added.
D, Phosphorus retained when 3.2 millimols of H_3PO_4 were added.

This behavior strongly indicates that the depressing effect which frequently results from light applications of lime to acid soils with colloids of high silica-sesquioxide ratio is caused by a decrease in the solubility of the phosphorus in the soil. If the soluble phosphate level is high, such as from a recent liberal application of a phosphate fertilizer, the depressing effect should not occur. The data definitely show that over-limed soils, i. e., soils with free $CaCO_3$ present after all the acids have been neutralized, would have little or no soluble phosphorus present.

Table 2 contains the data on the amount of phosphate retained by the high-iron content colloid. As in the case of the low-iron content colloid, the data obtained from the carbonated systems are most useful. These are graphed in Fig. 4. The most significant fact demon-

strated here is that the phosphate was retained at the very acid pH values by the iron. Since Gaarder (7) has shown that iron does not affect the retention of phosphates at the more alkaline reactions and since the behavior of these colloidal systems at the high pH values are similar to those discussed for Fig. 3, they will not be discussed here. In the Ca-series it will be noted that where the added phosphate concentration was greatest (25.8 millimols H_3PO_4 per 100 grams colloid), the carbonation reduced the amount of phosphate retained at the pH values of 4.0 to 5.0. This might be accounted for by the formation of iron carbonates, thus reducing the amount of free iron in solution that would otherwise precipitate the phosphate. This evidence would support an hypothesis that actively decaying organic matter in very acid soils by producing CO_2 would benefit the fertility of the soil with respect to phosphorus by reducing the amount of active iron in the soil. When the rates of added phosphate were low in the Ca-series, the tendency was for the phosphate in solution to increase with the increase in pH values. But the behavior at the highest pH value in the presence of free calcium carbonate in the two cases where the retention was not complete is not entirely clear. It will be noted, however, (Table 2) that the retention was complete before the systems were carbonated.

These data indicate that no depressing effect from light applications of lime should occur in soils that have a low silica-sesquioxide ratio. In fact, any decrease in acidity from the very acid pH values should be beneficial. The injury from over-liming should be the same as described before regardless of the nature of the colloidal fraction.

ANION EXCHANGE

REPLACEMENT OF PO_4 BY THE HYDROXYL ANION

The data in Table 1 and in Fig. 3 show that the maximum phosphate retention by the low-iron alumino-silicate colloid occurred at the slightly acid pH values. In the Na-series the maximum retention occurred at about pH 6.1. As the pH values increased above this value, i. e., as the OH anion concentration increased, the electrostatic sorbing forces on the colloid became satisfied with OH anions instead of phosphate anions. The attractive force for the phosphate anions was inversely proportional to the concentration of the hydroxyl anions, thus the increase of phosphate ions in solution with the increase in pH values can be looked upon as an anion exchange phenomenon.

REPLACEMENT OF PO_4 BY THE SILICATE ANION

Since it was found that the phosphate anions were held by the alumino-silicate colloids at a slightly acid reaction, it would be enlightening to learn if this phosphate could be replaced by another somewhat similar anion. It would be necessary to make such a test without changing the reaction, as it has been shown that the hydroxyl anion would replace the sorbed phosphate anion. Such a test was made using the silicate anion from sodium silicate. The scheme of this experiment is given in Table 3, which also shows the data obtained at the end of 8 days. To show the relation between phosphate

TABLE 2.—*Phosphate retained from solutions varying in concentrations of H_3PO_4 by electrodialized, high-iron content, ferriferated alumino-silicate colloidal systems that differ in pH values by the addition of $Ca(OH)_2$ and NaOH; data obtained before and after equilibration with CO_2 and reported on the basis of 100 grams of the colloid.*

M. Mols H_3PO_4 added	Calcium series							Sodium series						
	M.E. Ca added	Before carbonation			After carbonation			M. E. Na added	Before carbonation			After carbonation		
		pH	Cond. 30° C $X10^{-5}$	PO_4 retained M. Mols	pH	Cond. 30° C $X10^{-5}$	PO_4 retained M. Mols		pH	Cond. 30° C $X10^{-5}$	PO_4 retained M. Mols	pH	Cond. 30° C $X10^{-5}$	PO_4 retained M. Mols
3.2	0.0	3.4	15.0	3.2	3.2	16.7	3.2	0.0	3.3	13.7	2.8	3.2	20.5	2.5
	25.2	3.7	12.5	3.2	3.3	13.2	3.2	12.5	4.0	10.9	3.2	3.8	14.3	3.2
	50.5	3.9	10.9	3.2	3.5	11.1	3.2	25.0	4.4	9.8	3.2	4.3	10.9	3.2
	69.4	4.4	10.2	3.2	3.9	10.8	3.2	45.0	4.7	9.6	3.2	4.6	11.1	3.2
	84.1	5.4	8.4	2.7	4.6	9.5	2.6	70.0	5.3	10.6	3.2	5.0	12.6	3.2
	92.5	6.4	10.0	2.7	5.4	9.8	2.3	90.0	6.4	15.4	2.8	6.6	15.5	3.2
	111.2	7.8	17.8	3.2	6.1	16.4	2.2	105.0	8.5	22.6	0.6	7.6	28.9	—1.2
	157.6	10.3	21.2	3.2	8.0	36.7	1.6	155.0	10.7	76.0	—1.3	8.5	74.6	—9.0
6.5	0.0	3.3	16.3	6.5	3.1	21.8	6.5	0.0	3.3	14.0	6.0	3.2	16.1	5.7
	29.4	3.6	13.8	6.5	3.4	14.4	6.0	15.0	3.9	9.9	6.5	3.9	11.5	6.5
	54.0	3.9	11.0	6.5	3.7	11.2	6.0	30.0	4.3	9.1	6.5	4.2	14.2	5.8
	73.5	4.6	11.2	6.5	4.4	9.1	6.5	50.0	4.8	10.0	6.5	4.6	11.5	6.5
	88.4	5.6	9.6	5.8	5.9	9.8	4.9	80.0	5.8	11.7	6.5	5.3	13.7	6.5
	96.6	6.3	10.6	6.0	7.0	9.0	4.5	95.0	L	17.8	5.3	6.8	20.8	3.6
	126.0	8.7	12.6	6.5	7.3	19.1	4.1	110.0	9.0	31.8	—5.0	7.8	40.2	—2.9
	178.5	10.4	23.4	6.5	8.0	41.0	4.7	160.0	10.6	74.6	—6.5	8.5	75.0	—18.5
12.9	0.0	3.3	18.8	11.7	3.0	19.6	10.8	0.0	3.2	16.9	11.7	3.1	19.2	12.1
	44.2	3.7	12.3	12.9	3.6	12.2	12.2	20.0	3.8	11.1	11.9	3.7	15.8	12.9
	69.2	4.5	9.2	12.9	4.2	9.9	11.4	37.5	4.2	11.1	12.4	4.1	14.2	12.1
	86.2	5.2	8.9	12.9	5.1	9.9	12.1	55.0	4.8	10.8	12.4	4.5	11.9	12.9
	98.8	6.1	11.1	12.2	6.3	10.5	11.0	80.0	5.6	13.6	11.9	5.3	13.2	12.9
	111.2	7.1	13.2	12.4	7.2	12.1	10.5	95.0	6.5	19.2	10.1	6.7	22.0	11.4
	136.5	8.4	13.7	12.6	7.4	22.8	10.2	125.0	8.6	40.6	3.2	7.9	45.4	—7.7
	197.5	10.3	24.6	12.9	8.0	38.7	12.9	180.0	10.7	97.8	1.8	8.6	97.7	—22.4

	0.0	3.1	30.8	20.9	3.0	34.9	23.8	0.0	3.1	29.1	19.4	3.0	33.1	20.6
	65.1	3.6	16.7	24.9	3.5	19.3	22.8	35.0	3.7	18.0	21.0	3.7	19.1	22.6
	94.6	4.9	12.4	23.3	4.6	15.3	20.2	65.0	4.6	16.3	19.3	4.2	21.6	18.9
25.8	105.0	5.7	14.6	23.9	5.4	16.1	20.2	90.0	5.4	16.5	19.3	5.0	19.1	19.6
	126.0	6.5	14.8	23.9	6.5	15.8	23.0	111.0	6.6	27.7	15.8	6.4	33.1	14.2
	140.8	7.3	17.5	23.7	7.1	20.5	23.4	125.0	7.0	43.8	15.3	7.1	54.6	3.9
	172.1	8.0	18.0	24.5	7.4	23.1	24.0	155.0	8.7	65.2	0.9	8.0	83.8	—3.5
	232.0	10.4	24.2	25.8	8.0	41.5	25.8	215.0	10.8	130.0	1.6	8.6	119.4	—0.8

TABLE 3.—*The replacement of phosphate sorbed by the low-iron content alumino-silicate colloid by sodium silicate.*

Electro-dialized colloid, grams per 250 cc	Millimols H_3PO_4 added per 100 grams colloid	Approximate millimols SiO_4 added per 100 grams colloid	Cc of N/10 NaOH added per 250 cc to maintain	Tests 8 days after set-up		
				pH	Millimols PO_4 in solution per 100 grams colloid	Millimols PO_4 replaced by silicate per 100 grams colloid
2	6.5	0.0	16.0	6.1	0.71	Nil
2	6.5	4.8	14.1	6.1	0.92	0.21
2	6.5	9.6	12.2	6.1	0.95	0.24
2	6.5	19.3	8.9	6.1	1.01	0.30
2	6.5	38.0	1.5	6.0	1.05	0.34
2	0	38.0	0.0	6.2	Nil	—

anions replaced and the concentration of the silicate anions, the results are plotted in Fig. 5. The magnitude of the amount of the phosphate anions replaced was not great, but it will be noted that replacement actually occurred and the curve obtained is a characteristic double log curve.

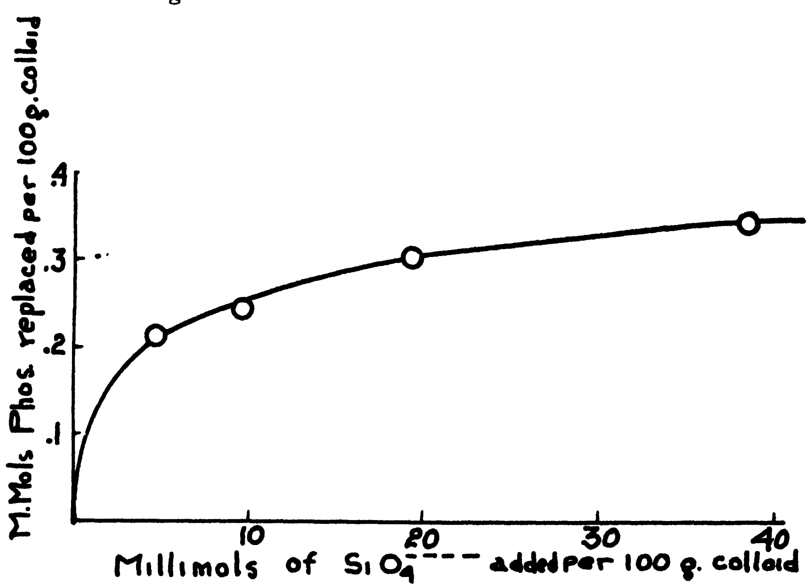

FIG. 5.—The replacement of the sorbed, insoluble phosphate on the low-iron content alumino-silicate colloid at pH 6.1 (pH changed with NaOH) by sodium silicate.

SUPPLEMENTARY DATA WITH PLANT TESTS

Four soils varying widely in several fundamental characteristics were studied in a greenhouse pot experiment to test out, by the use of growing plants, some of the findings in the laboratory investi-

gations with the colloids The principal object of these tests was to determine if the silicate anion would replace the native unavailable phosphate in various kinds of soils. The literature contains many references which show that silicates benefit plant growth and bear some relationship to the behavior of phosphates Schollenberger (17) gives a good review of this point However, this phenomenon has not been clearly demonstrated as an anion exchange reaction and it has not been shown how it is affected by the composition of the soil.

The soils used were Eutaw, Cecil, and Sumter clays, and Norfolk fine sandy loam At the bottom of Table 4 are given some of the data on the more fundamental characteristics of these soils Table 4 also shows the soil treatments, the yields of the sorghum crop after growing 97 days, and the available phosphorus (Truog's method) in the soil at the end of the test, 157 days after the soils were treated. The soils were treated 60 days before planting This was done in order that the added materials and the soil would have time to reach equilibrium

It will be noted that the "Promoloid,"[4] a colloidal magnesium silicate, and sodium silicate increased the growth of sorghum on only the Eutaw clay This increased growth from the silicates is attributed to an increase in the availability of the native phosphate in the soil The low yields on the no-phosphate treated pots and the amount of available phosphorus found in the soil of the silicate-treated pots are proofs of this A photograph (Fig 6), of some of the plants growing on the Eutaw clay shows further evidence of the replacement of the native phosphate in the soil

FIG 6 —Sorghum growing on the Eutaw clay, showing evidence of the replacement of insoluble native soil phosphates by a silicate Pot No 3, no phosphate, pot No 5, sodium phosphate, equivalent to 1 ton superphosphate per acre, pot No 35, 2 tons sodium silicate per acre, pot No. 41, sodium bicarbonate, rate equivalent to the sodium in pot No 35.

[4]Sample of Asahi Promoloid obtained from the Kawahara Company, Los Angeles, Calif.

TABLE 4.—*The replacement by silicates of natural phosphates in soils varying widely in certain important characteristics in a greenhouse experiment with sorghum as the test crop.*

Pot No.	Treatment*	Rate per acre to the Eutaw clay†	Eutaw clay		Cecil clay		Norfolk fine sandy loam, virgin soil		Sumter clay	
			Yields of sorghum, grams	Avail. P, lbs. per acre	Yields of sorghum, grams	Avail. P, lbs. per acre	Yields of sorghum, grams	Avail. P, lbs. per acre	Yields of sorghum, grams	Avail. P, lbs. per acre
3	No phos.	———	7.5	Nil	1.1	Nil	2.0	Nil	1.3	Nil
5	Na-phos.	Equiv. to 1 ton superphosphate per acre	64.0	24.3	21.6	19.2	18.1	3.2	32.6	6.4
11	"Promoloid" Mg-silicate	4,000 lbs.	15.5	Nil	1.1	Nil	1.7	Nil	1.5	Nil
13	"Promoloid" Mg-silicate	16,000 lbs.	53.4	5.1	0.6	Nil	1.5	Nil	1.5	Nil
19	$MgSO_4$	Mg equiv. to Mg in pot 11	14.1	Nil	1.7	Nil	1.7	Nil	1.7	Nil
21	$MgSO_4$	Mg equiv. to Mg in pot 13	15.8	Nil	2.0	Nil	1.2	Nil	1.3	Nil
33	Na-silicate	1,000 lbs.	12.8	3.2	1.4	Nil	1.2	Nil	2.2	Nil
35	Na-silicate	4,000 lbs.	42.7	5.7	0.5	Nil	0.6	Nil	8.3	Nil
39	$NaHCO_3$	Na equiv. to Na in pot 33	7.8	Nil	4.2	Nil	1.9	Nil	1.1	Nil
41	$NaHCO_3$	Na equiv. to Na in pot 35	16.2	Nil	4.1	Nil	0.7	Nil	2.0	Nil
Soil Characteristics:										
Colloid content, %			64.0		45.0		22.5		71.0	
SiO_2/R_2O_3 of colloid			2.3		1.37		1.16		2.38	
pH values			4.9		5.1		4.8		7.1	
Total base exch. cap. of soil			17.3		5.28		7.43		Contains free $CaCO_3$	
Total P_2O_5 cont., lbs. per acre			1,294		1,443		398		2,838	

*Each pot received nitrogen and potassium fertilization.

†The rates of applications were on the basis of equivalent units of material per unit of colloid instead of units of material per acre, thus a rate of 1,000 lbs. per acre to the Eutaw with a 64% colloid content would be 700, 445, and 1,110 lbs. per acre to the Cecil, Norfolk, and Sumter soils with 45, 22.5, and 71% colloid contents, respectively.

It is interesting and significant that the silicates were effective only in the Eutaw clay. Of the acid soils in this group, the Eutaw clay has the highest silica-sesquioxide ratio, 2.3; thus, its iron content is low in respect to its silicate content. In this sense, it represents more nearly the low-iron alumino-silicate colloid used in the laboratory than either of the other acid soils. In the high-iron colloid in the laboratory, the iron played the principal rôle in retaining the phosphate at the most acid reactions, and one would not expect a phosphate anion of precipitated iron phosphates to be as readily replaced by a silicate anion as when the phosphate anion was sorbed by some surface valences of a colloid. The colloidal fraction of the Cecil and Norfolk soils resemble the high-iron colloid used in the laboratory. In these soils, the free iron content is high in respect to the silicate content; note the silica-sesquioxide ratios of 1.37 for the Cecil and 1.16 for the Norfolk. The content of alumino-silicate complex of the Cecil and the Norfolk is low with respect to that of the Eutaw as indicated by the total exchangeable base capacities of the soils, which are 5.28, 7.43, and 17.3, respectively. (The higher value for the Norfolk fine sandy loam than for the Cecil clay is accounted for by the fact that the Norfolk was taken from a virgin area and contained more organic matter than the Cecil.) The relative abundance of an alumino-silicate complex is important as it was shown in the laboratory investigations that it plays an active part in phosphate retention in acid systems where the free iron content is low.

It is also of interest to note that the growth made on the soils that did not receive any phosphorus (pot No. 3) was 7.5, 1.1, and 2.0 grams on the Eutaw, Cecil, and Norfolk, respectively. This again agrees with the interpretation of the data from the colloidal systems used in the laboratory. The native phosphorus in the Eutaw clay, where the silica-sesquioxide ratio was high, was more available than that in the Cecil and Norfolk soils with low silica-sesquioxide ratios. This was shown by the differences in the growth made by plants on the three soils when phosphorus was not added.

The results with the Sumter clay, a soil that contains an abundance of free $CaCO_3$, show no benefits from the silicates, except in the case where the sodium silicate had been added at the rate of 2 tons per acre. Here the presence of sodium ions with the calcium ions would explain the results in that the sodium formed some soluble sodium phosphates from the calcium phosphates in the soil. This soil contains more natural phosphate than any of the soils in the experiment. This soil is comparable to the low-iron colloids containing an excess of $CaCO_3$ which fixed all the phosphate added.

DISCUSSION

MECHANISM OF PHOSPHATE RETENTION

If the data for the Na-series of Fig. 3 are plotted to show the relation between the amount of phosphate ions sorbed by the colloid and the amount of phosphate ions in solution at the pH value where the maximum sorption occurred, a curve as shown in Fig. 7 is obtained. This curve shows that this alumino-silicate colloid has a

sorption capacity of 10 millimols of PO_4 or 30 M. E. of anions per 100 grams of the colloid. In Fig. 1 it appears that the cation sorption capacity of this colloid is about 100 M. E. per 100 grams, thus the anion sorption capacity of the colloid in the presence of a monovalent cation, Na, is approximately one-third of the cation sorption capacity.

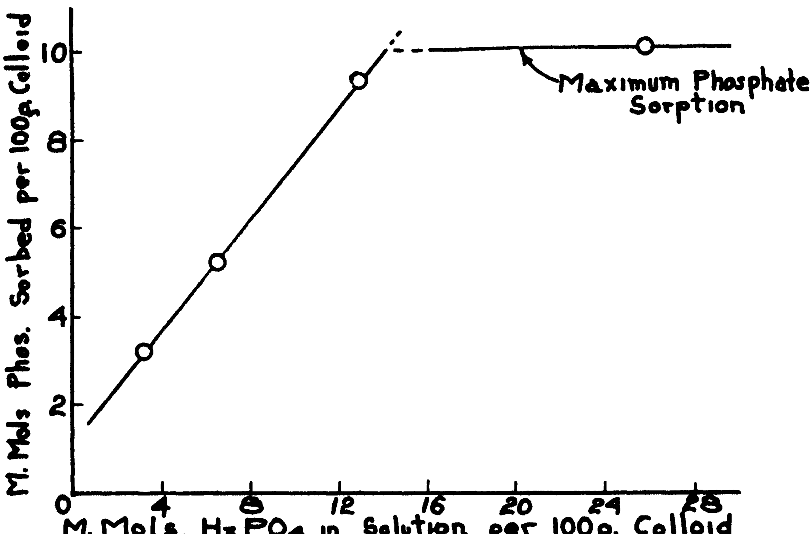

FIG. 7.—The relation between the concentration of phosphate ions in solution and the amount of phosphate ions retained by the low-iron content alumino-silicate colloid at pH 6.0 in the presence of sodium ions. The maximum phosphate capacity (anion sorption capacity) of the colloid in the presence of a mono-valent cation (Na) appears to be 10 millimols of PO_4^{---} or 30 milliequivalents of anions per 100 grams of the colloid.

It will be noted in Fig. 3 that the maximum deflection in the curve for the highest phosphate rate in the Ca-series occurs farther up on the graph than in the case with the Na-series. (It is apparent that the maximum sorption capacity for the alumino-silicate complex cannot be measured by the present method when a divalent cation is sorbed by the complex.) This indicates that the phosphate is also held by one of the valences of the calcium as the latter shares its two valences with the phosphate anion and the complex. These evidences form the basis for the writer's concept of the mechanism involved in the retention of phosphates by the colloidal systems studied; this concept is set forth in a series of idealistic diagrams in Fig. 8.

The atomic structure of the alumino-silicate complex is hypothetical, as pointed out by Brown and Byers (5), but it serves to express the chemical relationships that exist on the surface of the colloids. The silica-alumina ratio of the tested colloid was 4.5. This ratio in the diagrams is 4.0. The difference could easily be accounted for as free silica in the bentonite colloid. The cation-anion ratio in the diagrams

is made to be 3.0; for the tested colloid it was 3.03. The H symbols represent exchangeable hydrogen or cation valences and the symbol X represents a continuation of the alumino-silicate complex into the colloidal crystal.

At pH 6.0, when the cation valences of the complex are practically saturated with hydrogen, the PO_4 anions are not sorbed. (See

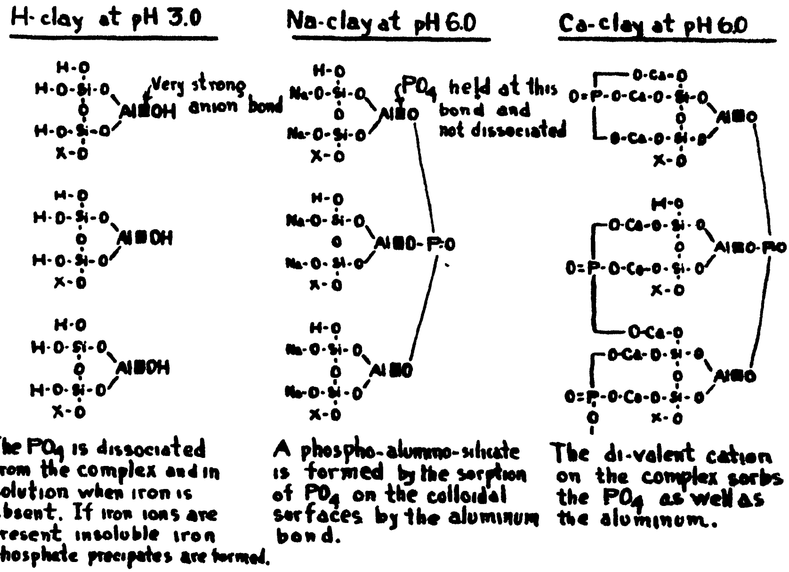

FIG. 8.—Diagrams of the apparent mechanism of phosphate retention by the alumino-silicate colloid when unsaturated or partially saturated with sodium or calcium. X represents the continuation of the alumino-silicate complex into the colloidal crystal.

Fig. 3.) The anion valences must be satisfied with OH anions which are held with a very great electrostatic force since here the hydroxyl anions are not dissociated. The PO_4 ions will remain in solution unless the environment contains iron, in which case insoluble iron phosphates are formed. (See Fig. 4.)

At pH 6.0, when the complex is partially saturated with Na, the aluminum bond of the colloidal complex sorbs the PO_4 anion. This extremely complex colloid can be thought of as an alumino-phospho-silicate. Since the cation is mono-valent and thus has no residual bond for other anions, and since any sodium phosphate that may be formed is soluble, it follows that the retention of the phosphate can be only by the colloid. Gaarder (7) has shown that the maximum insolubility of the phosphate anions occurs at a pH between 5.0 and 6.0 when there is an excess of aluminum present, and the basic ion present is Na. Thus, the evidence indicates that it is the aluminum valences in the surfaces of the colloid that retains the PO_4 in the low-iron colloids used. In normal soils free $Al(OH)_3$ would also retain phosphates.

At pH 6.0, when the complex is partially saturated with Ca, the PO_4 is retained by the aluminum bond as in the case with the Na-clay, but, as is shown in Fig. 3, the sorption capacity is greater when the cation on the complex is di-valent than when it is mono-valent. The greater sorption capacity by the Ca-clay appears to be caused by the retention of the phosphate by the Ca that is sorbed on the complex.

The data do not clearly indicate whether the phosphate is sorbed as a mono-, di-, or tri-valent anion. The investigations of Steele (18), which have been conducted in close coordination with the present study, indicate that the phosphate is sorbed by clays as the tri-valent anion.

At the higher pH values the PO_4 retained by the colloid complex is replaced by the OH anion. This was proved earlier in this paper and is evident in the curves of Fig. 3. If the basic ions are Ca, the PO_4 ions replaced by the OH are precipitated as insoluble calcium phosphates. When the colloid systems contain free $CaCO_3$, all of the PO_4 ions are precipitated.

This concept of the mechanism of the retention of phosphates by the alumino-silicate colloid is essentially in agreement with the results of Ungerer and Bradfield. Ungerer (19, 20) showed that K-permutite and NH_4-permutite increased the amount of P_2O_5 in solution when the permutites were added to the insoluble phosphates of lithium, magnesium, calcium, strontium, and barium. Bradfield (3) found that SO_4 and C_2O_4 anions of such insoluble salts as $BaSO_4$ and CaC_2O_4 were brought into solution in appreciable amounts by a Na-clay (bentonite) and that the exchanged cations were retained by the clay. Their results can be explained as a double decomposition reaction with the formation of a more soluble phosphate from ionic exchange.

RELATION OF PHOSPHATE SOLUBILITY TO LIMING INJURY

It has been pointed out that changing the reaction of soils having a colloidal fraction with a high silica-sesquioxide ratio from very acid (pH 3.0 to 5.0) to slightly acid (pH 6.0) will cause a depression in the amount of soluble phosphorus. This depression is caused by bringing the reaction to the point where the alumino-silicate complex exerts its maximum phosphate-sorption tendency. This fact is proved in the Ca-series (Fig. 3) and is demonstrated (Fig. 9) by the yields of oats on a heavy clay soil that had a silica-sesquioxide ratio of 2.3 for its colloidal fraction. It will be noted in Fig. 9 that liming the soil to pH 6.0 caused a great depression in the plant growth when the amount of available phosphate supplied was relatively low. When the available phosphate level was high, as represented by the greatest rate of application of the phosphate fertilizers, liming the soil to pH 6.0 did not decrease the yield; on the contrary, it increased the yield. Other investigations by the author (15) have shown that over-liming the soil to the extent that it contains free $CaCO_3$ after all the soil acids have been neutralized causes a great deficiency in the available phosphate. The injury from over-liming tends to be

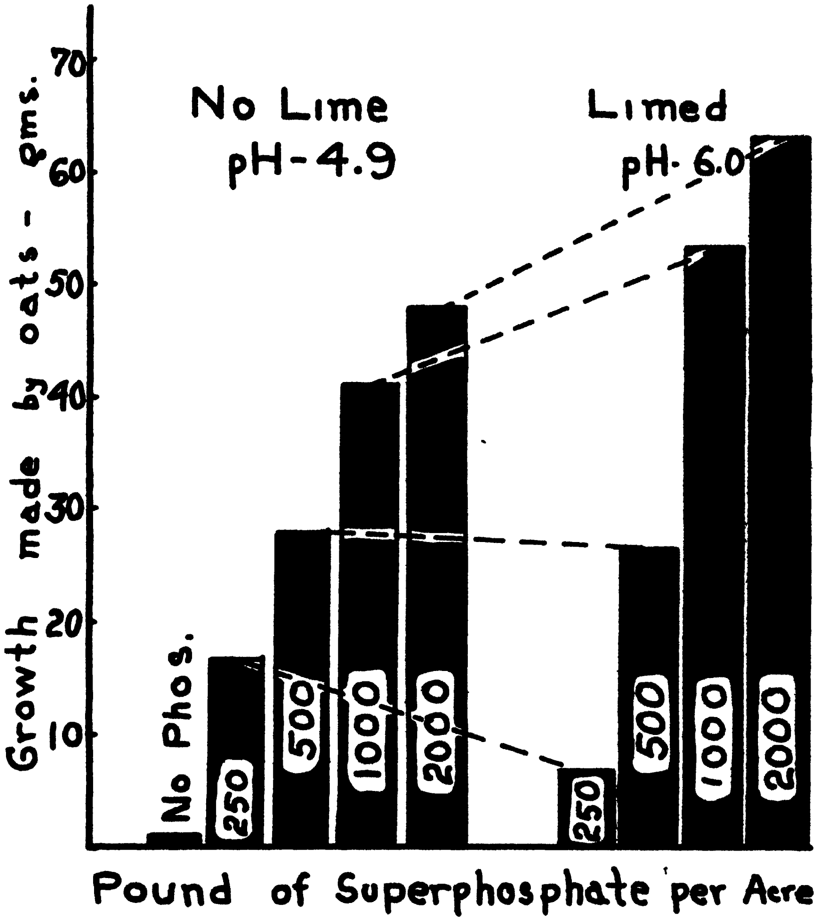

FIG. 9.—The growth made by oats in greenhouse test pots on a 60% colloid content soil that has a high silica-sesquioxide ratio (2.3) where various levels of soluble phosphate have been applied without lime and with lime. The lime depressed the growth where the amount of applied phosphate was low and increased the growth where the amount of applied phosphate was high.

somewhat temporary and becomes less as the soil solution becomes less alkaline. It is important to recognize the differences involved in respect to the relationship of the behavior of the phosphates to the injury from liming, since in one case the injury results merely from changing the reaction and in the other case from the presence of free carbonates.

PRACTICAL ASPECTS OF ANION EXCHANGE

The fact that the native unavailable phosphates in certain soils can be replaced by other anions presents a practical approach to the problem of maintaining a high level of available phosphorus in heavy

clay soils that have a colloidal fraction with a high silica-sesquioxide ratio. It may be practical to add silicates to such soils; also it may be that the addition of blast furnace slag, which is a calcium silicate, to mixed fertilizers as a filler may have some advantages in increasing the availability of the natural soil phosphates and in retarding the rate of fixation of the applied phosphate. Other commercial forms of silicates may be found valuable in this connection.

The benefits derived from organic matter may be attributed in part to the humates replacing phosphates since the humates are anions that may be sorbed similarly to the phosphate anions.

It is apparent that in order to apply the principles set forth in this investigation to normal soils it is necessary to have considerable information on the fundamental characteristics of the soil colloids.

SUMMARY

The colloidal clay fraction of a natural alumino-silicate (bentonite) was freed from all mobile ions by electrodialysis and made into 16 series of 0.8% suspensions with eight individual treatments in each series. The concentrations of phosphate, sodium, calcium, and hydroxyl ions were varied systematically. At equilibrium, tests were made to determine the amount of phosphate ions retained by the colloids, the pH values, and the conductivity of the different systems both before carbonation and after carbonation when equilibrium with the CO_2 of the air was attained.

The alumino-silicate colloid was found to sorb the phosphate ions. Maximum retention occurred between pH 5.2 and 6.1 when Ca ions were the exchangeable cations present and at about pH 6.1 when Na ions were present. The anion sorption capacity in the presence of the Na ions was found to be approximately one-third of the cation sorption capacity. The Ca ions greatly increased the phosphate sorption capacity of the colloidal complex in the acid range. At the point where the cation valences were saturated with Ca ions (pH 8.2) the concentration of phosphate ions in solution decreased as the concentration of the unsorbed Ca ions increased, due to the formation of insoluble calcium phosphates. All the phosphate was insoluble when the system contained free $CaCO_3$. No insoluble phosphates were formed at the high pH values when Na ions were the cations used.

The phosphate retained at the pH values of 5.5 to 6.1 is believed to be sorbed on the colloidal surfaces of the alumino-silicate by the aluminum valence. The phosphate ion was found to be exchangeable and was replaced by OH and SiO_4 anions.

The retention of the phosphate ion by the colloid was greatly increased when the alumino-silicate was enriched with iron. With Ca on the clay complex and after the systems that received 25.8 millimols of H_3PO_4 per 100 grams of colloid had been carbonated, the minimum retention occurred between pH 4.0 and 5.5. The formation of $Fe_2(CO_3)_3$ from the carbonation treatment lowered the concentration of iron ions, thus permitting a greater amount of phosphate ions to remain in solution. The maximum retention occurred at pH

3.0 where insoluble iron phosphates were formed and at pH values above 8.0 where insoluble calcium phosphates were formed in the presence of $CaCO_3$. This would indicate that injury from "overliming" may be caused by a deficiency in available phosphates to the plant.

The data show that plant injury from light applications of lime is caused by a decrease in the availability of the phosphate and is likely to occur only in soils relatively low in sesquioxides. Changing the pH from 4.0 to between 5.5 and 6.2 caused all the phosphate to be retained by the low-iron colloid when the amount of phosphate added to the system was relatively small; but when the amount of phosphate added was large, the retention was not nearly complete.

The phenomenon of the replacement of the phosphate anion from the alumino-silicate colloidal systems by the silicate anion as found in the laboratory studies was verified with four soils in greenhouse pot tests with sorghum plants. The most outstanding phosphate replacement resulted on a very acid, heavy clay soil with a silica-sesquioxide ratio of 2.3, where sodium silicate produced a growth without a phosphatic fertilizer almost equal to that on the phosphate-fertilized soil.

A concept of the mechanism of the retention of phosphates by soil colloids is set forth and some practical aspects of anion exchange are suggested.

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LOCAL VARIABILITY IN THE PHYSICAL COMPOSITION OF WISCONSIN DRIFT[1]

ERIC WINTERS AND HERMAN WASCHER[2]

DURING the course of the soil survey of Ford and Vermilion counties, Illinois, in 1929 and 1930, marked differences were noted in the character of the unleached glacial drift; differences which could not be explained as being due to separate and distinct glacial advances because they did not coincide with the morainal lines. Moreover, within a given area the depth to unleached material appeared to be governed, not by any possible difference in age, but by variations in the permeability of the drift.

Field observations indicated that soil types correlated with the variations in the character of the parent glacial till. According to Marbut (3)[3] and others, parent material is of minor importance in soil classification after the climatic forces of weathering have acted a sufficient time to impress those features, which they are capable of impressing, on the soil profile. However, in a geologically young region such as that part of northeastern Illinois covered by the Wisconsin drift sheet, the character of the parent material has had a strong influence on the character of the soils developed from it. In the region studied, free carbonates occur at 2 to 4 feet below the surface and their presence at this depth indicates that here the parent material is still exerting a strong influence in the soil profile and will continue to be of major importance in its development for a long time. Subdrainage and the effectiveness of tile in this region depend in a large measure on the permeability of the unleached drift substratum, consequently the agricultural value of the land is largely dependent on the character of this underlying drift.

The significance of this conclusion is emphasized by the data of Stauffer (5) which show that the physical properties of the soil profile are closely correlated with the properties of the underlying drift. Krumbein (1) analysed samples of till from several areas of the Wisconsin advance and his data also show marked variations in drift composition. He pointed out that certain regional drift separations probably could be made, but neither he nor Stauffer attempted to outline the local distribution of the several types of drift.

Little other accurate data on the mechanical composition of glacial drift are available. Results obtained by the older sedimentation methods are of limited value because dispersion, particularly of the clay, was variable and incomplete.

PROCEDURE

The northwest portion of Vermilion County, Ill., is a region in which the drift is very heterogeneous and this area was chosen for intensive study. Numerous

[1]Contribution from the Division of Soil Physics, Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Received for publication May 20, 1935.

[2]Assistant and First Assistant, respectively.

[3]Reference by number is to "Literature Cited," p. 622.

sections were examined in the field in an attempt to separate the drift into groups by the handling properties, such as plasticity and compaction. Under varying moisture conditions this proved difficult, particularly without type sections of known properties for reference. Therefore, to supplement the field work, samples for mechanical analysis were taken with a spade, as outlined by Krumbein (1) and as practiced by the Illinois Soil Survey for many years, from certain sections thought to be representative, as well as from others of doubtful and unusual character. In all cases the material represents calcareous till and lies within the D horizon as defined by Norton and Smith (4). This corresponds to horizon 4 in the terminology of Leighton and MacClintock (2), and in this region lies at an average depth of 3 feet.

The method of Winters and Harland (6), omitting the HCl pretreatment, was used in making the mechanical analyses, the results of which are reported in Table 1. Since these samples contained very little material larger than 2 mm and in some cases none at all, coarse gravel has been neglected in calculating the percentages. Silt (0.05 to 0.005 mm) is not reported, but may be found by taking the difference between 100% and the sum of the sand and clay fractions. The figures in column 2, which give the approximate free carbonate content, were calculated from the carbon dioxide evolution in terms of calcium carbonate equivalent.

DISCUSSION

In Table 1 the data are arranged in ascending order of the content of colloidal material. The trend of the sand content thus becomes, in general, descending with an occasional exception, but these deviations are hardly large enough to be of importance. The free carbonates fall in most cases between 18 and 25%, showing that these samples are relatively unleached and unweathered as mentioned above. Those cases where the carbonates are low might be interpreted as resulting from partial leaching, or else the original sediments may have been less calcareous. The fact that the low carbonate samples are usually high in colloids lends probability to the latter suggestion.

It is clear that no till groups can be defined merely by an inspection of the data in Table 1. In fact the variation from sample to sample is so gradual and regular that the impression is one of a continuous series rather than definite groups. Perhaps such a situation might be expected from a knowledge of the origin of drift. The variation in the surficial material and the lack of uniformity in the degree of grinding and mixing by the glacier must have presented the possibilities for a resulting drift of almost any imaginable composition.

To help judge the significance of the data in regard to the rate of percolation of water, it will be helpful to compare them with the analyses of soil horizons whose permeability is known. Impermeable subsoils of Putnam silt loam from southern Illinois have been examined and none show more than 55% clay; in fact, few exceed 50%. Their colloid content, however, runs from 38 to 43%, though it must be said that the base saturation is low, indicating a highly dispersed condition. The rather slowly permeable subsoils of Grundy silt loam from west-central Illinois are saturated with bases, these horizons containing 45 to 48% clay and 35 to 37% colloids.

It will be noted that the colloidal contents in Table 1 approximate one-half the clay percentages, a relationship that also holds in surface soils which have undergone considerable eluviation. In illuviated and in less strongly eluviated soil horizons, the colloids usually account for two-thirds or more of the clay. The suggestion is offered that this is so because glacial action was severe enough in the region under discussion to pulverize many of the sedimentary rocks to clay size, but that colloids originate chiefly through chemical weathering. Therefore, somewhat different criteria must be used

TABLE 1.—*Mechanical analysis of Wisconsin drifts in Vermilion County, Ill.*

Sample No.	$CaCO_3$ equivalent %	Mechanical analysis		
		Sand, 2.0–0.05 mm, %	Clay, 0.005 mm, %	Colloid, 0.001 mm, %
		Elliott		
1	23.2	17.7	37.4	18.2
2	24.5	12.4	35.6	18.5
3	19.6	16.3	38.0	20.0
4	24.5	7.4	47.0	22.8
5	22.3	15.0	45.8	23.1
6	23.2	11.2	50.0	24.2
7	25.0	7.9	51.0	25.0
8	20.5	7.6	49.8	25.3
9	22.8	8.6	51.4	26.2
10	19.6	8.4	51.5	26.4
		Plastic Elliott		
11	21.9	7.3	53.0	27.3
12	27.6	7.4	50.8	27.6
13	22.0	5.2	54.4	27.8
14	22.4	5.4	51.1	28.1
15	21.6	2.2	56.5	29.1
16	21.4	7.1	56.2	29.2
17	23.4	8.8	55.2	29.4
18	20.0	7.8	56.4	30.4
19	22.9	7.6	62.3	30.6
20	—*	7.4	57.8	30.0
21	22.3	7.6	58.4	31.3
22	23.6	7.3	58.2	31.6
23	12.0	7.2	59.1	31.8
		Clarence		
24	18.4	6.2	61.5	32.8
25	21.7	5.9	64.0	33.8
26	21.0	5.5	63.0	34.8
27	18.9	5.2	70.8	35.6
28	21.4	5.2	65.8	35.8
29	21.5	5.2	66.0	35.8
30	19.5	4.8	68.2	38.1
31	—*	4.7	70.7	41.2
32	—*	2.2	76.2	41.6
33	19.5	2.3	78.8	42.4
34	6.2	3.1	74.0	43.7
35	16.7	3.5	80.3	43.7
36	11.4	3.2	80.5	54.5

*Not determined.

in judging the permeability of till on the basis of mechanical analyses than are applied to most soil horizons since the ratio of colloid to clay is so different. Observations were made in the field at the various sampling localities of the drainage characteristics of the till and the overlying soil. Bringing all the evidence together, it seems reasonable to expect that a clay content of 50% or more will be associated with rather slow percolation in this region. As the clay reaches 65 to 70%, the colloid usually is about 35% and percolation becomes extremely slow, in fact quite comparable to the southern Illinois subsoils mentioned above.

Sand does not seem important in affecting permeability until it exceeds at least 10%, hence it is seldom of concern in the profiles high in clay content. However, when the clay falls below 40%, as with the samples at the top of Table 1, some attention must be paid to sand. Thus, the first three samples are approaching moderate permeability.

Combining field observation and laboratory data, four groups of till have been set up and are defined as follows:

1. Clarence—Impermeable, plastic	Clay	> 60–65%
	Colloid	> 34–31%
2. Plastic Elliott—Slowly permeable, plastic..	Clay	> 50–54%
	Colloid	> 28–26%
3. Elliott—Slow to moderate permeability....	Clay	> 36–38%
	Colloid	> 18–16%
4. Saybrook—Permeable..................	Clay	< 36–38%
	Colloid	< 18–16%
	Sand	> 15%

No samples of Saybrook are included in Table 1, though the first three are approaching this group in properties.

The groups exhibit color differences as well as differences in plasticity which are helpful in field identification. Clarence is invariably gray, while Saybrook is distinctly yellowish[4] and this, in conjunction with the associated plasticity and textural properties, make these two groups very distinctive. As might be expected, the color grades gradually through the Elliott groups just as do the clay contents.

Sample No. 36 in Table 1 is worthy of special attention. It is from a layer of plastic material about 2 feet in thickness having calcareous Elliott both above and below. It is exposed in a road cut near Armstrong and is very conspicuous. Its low carbonate content in view of the absence of any possibility for leaching strengthens the suggestion previously made that Clarence often may be low in limestone and high in shale compared to Elliott.

The location of the samples in Vermilion County is given by number in Fig. 1. The outlines of each group as determined by a rather

[4]Saybrook drift in the western part of the Wisconsin area is pink tinged.

detailed field survey, using the laboratory data as a guide, are also indicated. The areas are neither continuous nor abruptly demarked. This may be interpreted to mean that all the drift of the region belongs to the same glacial advance and varies little if any in age. Some samples appear to be within the wrong boundaries according to their analyses (Nos. 6, 8, and 19, for example), but this results

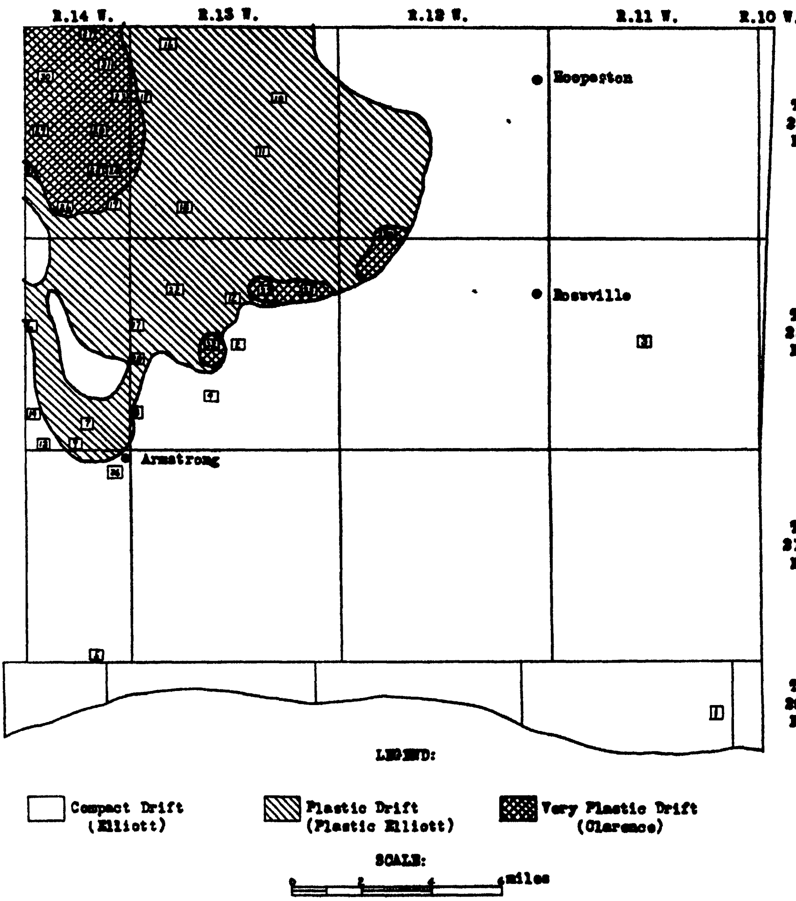

FIG. 1.—Northern portion of Vermilion County, Illinois, showing distribution of drift groups.

from the occurrence of sharp local variations. Attention is called to Nos. 2 and 32 located close together yet extremely different in composition. The difficulty of placing the intermediate samples as Nos. 6 and 8 in the right group is often considerable and emphasizes the fact already pointed out that local variations within the drift do occur and that the drift groupings must often be more or less arbitrary.

The practical significance of these arbitrary groupings might be questioned. Since this study was started the field work of the Soil

Survey has included counties in other parts of the Wisconsin drift area. This work, which will be reported on in detail in a later paper, has indicated that erosion is less destructive, tile are more effective, and crop yields are higher on soils developed from so-called Saybrook drift than those developed from so-called Elliott drift when considered under the same conditions of topography and native vegetation. Similarly, soils developed from Elliott are more desirable than those developed from Plastic Elliott and Clarence drift. Thus, the major soil divisions of the region have come to be based upon the physical composition of the drift from which the soil is developing as this has proved the most usable criterion in making regional separations.

SUMMARY

Mechanical analyses for 36 samples of glacial till are presented which show the wide range in physical composition of Wisconsin drift within a small area. Using these analyses in conjunction with field observations, four till groups have been defined whose properties are different enough to form the basis for soil series separation in the region.

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NON-ACID-FORMING MIXED FERTILIZERS: I. THEIR EFFECT ON CERTAIN CHEMICAL AND BIOLOGICAL CHANGES IN THE SOIL-FERTILIZER ZONE AND ON PLANT GROWTH[1]

J. R. TAYLOR, JR., AND W. H. PIERRE[2]

THE problem of fertilizer acidity has become of increasing importance in recent years. Although the general problem has received considerable study, new questions have arisen as a result of the rapidly increasing use of dolomitic limestone in the production of non-acid-forming fertilizers and the tendency to concentrate the fertilizer in narrow bands along the row. Foremost among these is the effect of potentially neutral fertilizers containing dolomitic limestone supplements on chemical and biological changes in the zone of fertilizer incorporation and the resulting effect upon plant growth.

In general, dolomitic limestone supplements have been considered to be beneficial in two respects, *viz.*, (a) the dolomitic limestone is valuable in neutralizing the acidity produced in the soil by the fertilizer, and (b) it supplies magnesium, an element that in recent years has been found to be deficient in certain soils of the eastern states. In addition to these two functions it is possible, as some of the data obtained in this investigation indicate, that dolomitic limestone supplements may be valuable in other respects.

Although the amounts of limestone added to the soil through the use of non-acid-forming fertilizers are low on the acre basis, it should be recognized that the concentration of limestone in the zone of fertilizer incorporation is high in many cases. This may be expected to become increasingly true as a result of improvements in fertilizer distributing machinery and the tendency to concentrate the fertilizer in narrow bands along the row. Any changes in the soil in the fertilizer zone resulting from the presence of dolomitic limestone in the fertilizer would, therefore, be much greater when the fertilizer is applied in the row than when applied broadcast.

The purpose of this investigation was to compare the effects of acid-forming and potentially neutral fertilizers when added in concentrations comparable to those found in the soil-fertilizer zone under row or hill fertilization upon the following: (a) Nitrification of added ammonia; (b) pH value; (c) concentration of water-soluble magnesium, calcium, and phosphate; and (d) plant growth.

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[1]Contribution from the Department of Agronomy and Genetics, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Published with the approval of the Director as Scientific Paper No. 151. Also presented before the Division of Fertilizer Chemistry at the Eighty-eighth meeting of the American Chemical Society, Cleveland, Ohio, September 10 to 14, 1934. Received for publication July 6, 1935.

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EXPERIMENT I. EFFECT OF ACID-FORMING AND POTENTIALLY NEUTRAL FERTILIZERS ON NITRATE PRODUCTION, H-ION CONCENTRATION, AND SOLUBLE MAGNESIUM IN UNCROPPED SOILS

METHOD OF PROCEDURE

A Dekalb silt loam soil of pH 4.85 and a Dekalb loam of pH 5.58 obtained from the Agronomy Farm were used in these studies. The two principal fertilizers used analyzed 6–8–6 and were made up with superphosphate as the source of phosphorus, muriate of potash as the source of potash, and urea and ammonium sulfate as sources of nitrogen. One-third of the nitrogen was from urea and two-thirds from ammonium sulfate; therefore, the equivalent acidity was 500 pounds $CaCO_3$ per ton. Sand was used as filler in the case of the acid-forming fertilizer and dolomitic limestone was used for the potentially neutral fertilizer. The dolomitic limestone analyzed 22.1% MgO and 30.9% CaO. It all passed through a 40-mesh sieve; 16.3% was held on a 60-mesh sieve, 14.0% on an 80-mesh sieve, 6.7% on a 100-mesh, and 63.0% went through a 100-mesh sieve. In addition to the two complete fertilizers, an 0–8–6 fertilizer carrying the same amount of superphosphate and muriate of potash as the former, but carrying no nitrogen nor dolomitic limestone, was used in order to serve as a check on the effect of the nitrogenous portion of the fertilizer.

The fertilizers were applied at such rates as to represent in a general way the concentrations of fertilizer in the zone of incorporation as obtained under common fertilizer application practices. Although such practices vary so widely that any rates selected must be considered arbitrary, it was possible to select what are believed to be reasonably representative values through a study of data kindly furnished by Dr. G. A. Cumings of the Bureau of Agricultural Engineering.[3]

The rates adopted were arrived at as follows: Acre applications of fertilizer are usually based on a weight of 2,000,000 pounds, which represents a volume of soil 6⅔ inches deep over an acre. In row fertilization, however, only a small part of the soil to a depth of 6⅔ inches is mixed with the fertilizer. With rows 36 inches apart, the total cross-sectional area for one row to a depth of 6⅔ inches is 240 square inches. Assuming the total cross-sectional area fertilized to be 5 to 20 square inches for potatoes, 10 to 15 square inches for cotton, and 2 to 10 square inches for corn, it is found that of the total cross-sectional area only the following portions are fertilized: 1/48 to 1/12 for potatoes, 1/24 to 1/16 for cotton, and 1/120 to 1/24 for corn. If acre rates of 1,000 pounds are taken for potatoes, 400 pounds for cotton, and 200 pounds for corn, the rate of fertilization on the basis of the fertilized zone would become 48,000 to 12,000 pounds per 2,000,000 pounds of soil for potatoes, 9,000 to 6,400 pounds for cotton, and 24,000 to 4,800 pounds for corn.

From a consideration of these values it was decided to use the different fertilizers on the Dekalb loam (No. 745) at the rates of 5,000 and 20,000 pounds per 2,000,000 pounds of soil and on the Dekalb silt loam (No. 744) at the rate of 20,000 pounds, these rates representing the concentration of fertilizer which may be found in the soil-fertilizer zone under average conditions. If it is assumed that in hill or row applications the fertilizer is mixed with only one-tenth of the surface 6⅔ inches of soil, the total amounts applied would correspond to 500 and 2,000 pounds per acre; if mixed with one-twentieth, to 250 and 1,000 pounds per acre, respectively. Hereafter, in this experiment the 5,000-pound application will be

[3]Private communication.

referred to as the low rate of fertilization, and the 20,000 pounds as the high rate of fertilization.

The fertilizers were thoroughly mixed with separate 200-gram samples of each soil, the mixtures placed in small glass containers, and distilled water added to bring the soils to approximately optimum moisture content. The containers were then placed in an oven maintained at a constant temperature of 30° C. Distilled water was added from time to time to compensate for the amounts lost by exaporation. All treatments were in duplicate. After various intervals the soils were dried

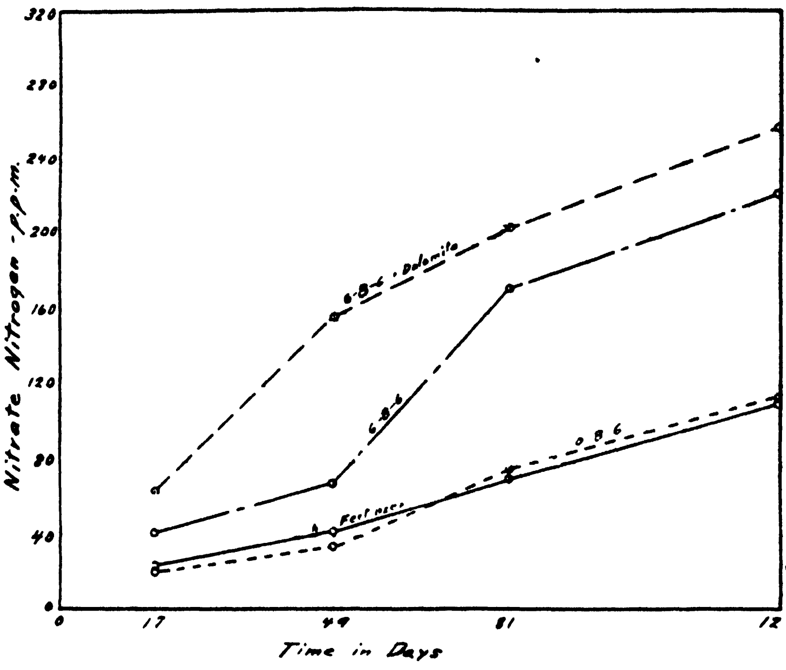

Fig. 1.—Nitrification in fertilizer zone after various intervals; soil 745, Dekalb loam; low rate of fertilization.

and samples removed for studies of pH, nitrification, and the concentration of water-soluble magnesium.

The water extracts of the soils were obtained by the dialysis method (8)[4] after the soil had been in contact with the water for 18 hours in the presence of sufficient toluene (1 cc per 125 cc water) to prevent denitrification. The pH was determined by the colorimetric method (8), nitrates by the phenoldisulfonic-acid method, and magnesium by the method described by Kramer and Tisdall (3).

EXPERIMENTAL RESULTS

Nitrate accumulation in the soil-fertilizer zone.—The amount of nitrates produced in the soil-fertilizer zone after various intervals is shown in Figs. 1 and 2 for the two rates of fertilization of the medium-acid Dekalb loam and in Fig. 3 for the high rate of fertilization of the strongly-acid Dekalb silt loam. In all cases it will be noted that the non-acid-forming fertilizer, which contained dolomitic limestone,

[4]Figures in parenthesis refer to "Literature Cited," p. 641.

caused a much greater nitrification of the ammonia added than did the acid-forming fertilizer of similar analysis. This is especially noted

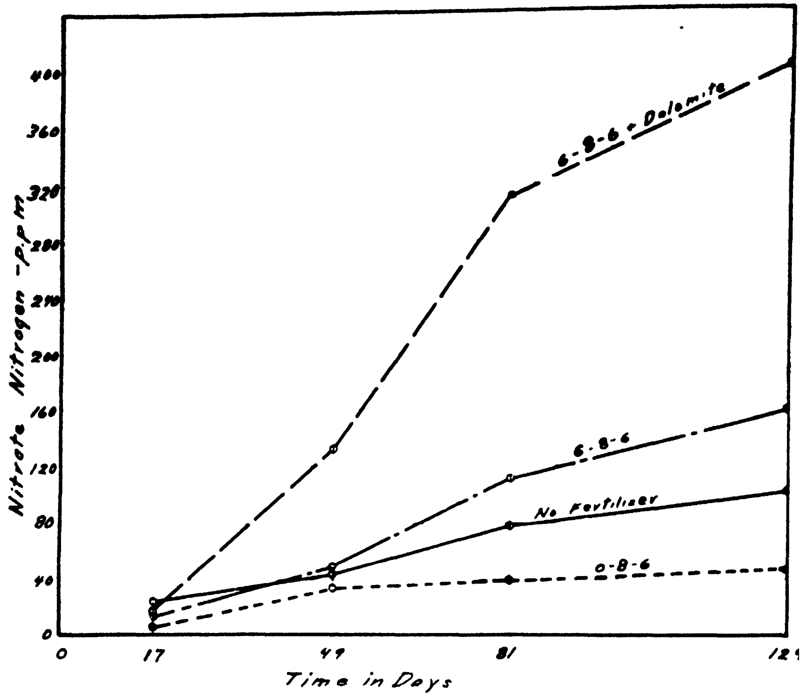

FIG. 2.—Nitrification in fertilizer zone after various intervals; soil 745, Dekalb loam; high rate of fertilization.

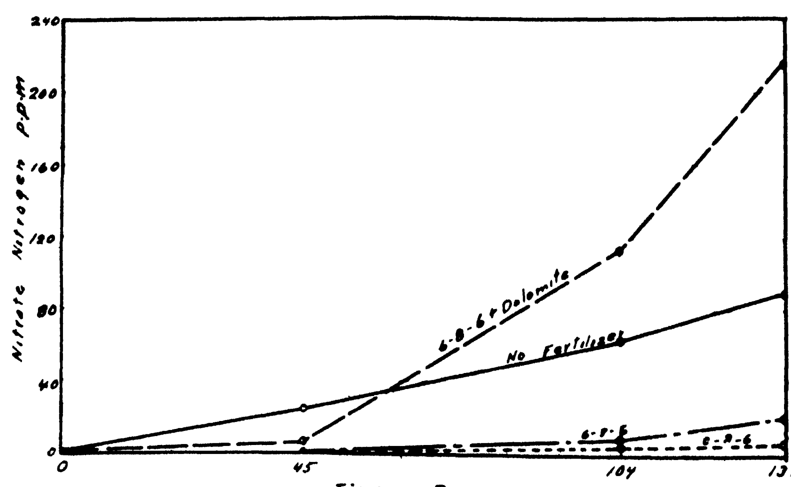

FIG. 3.—Nitrification in fertilizer zone after various intervals; soil 744, Dekalb silt loam; high rate of fertilization.

in Figs. 2 and 3 where the high rate of fertilization was used. The high salt concentration developed in the fertilizer zone from the high rate of fertilization inhibited nitrification on these acid soils. Thus, with both soils, the amount of nitrates produced was considerably lowered where the 0-8-6 fertilizer was used than where the soil received no treatment.

In Table 1 the data presented in the graphs are briefly summarized. The amounts of the added nitrogen which were nitrified after various intervals were calculated by subtracting the nitrates in the cultures receiving the 0-8-6 fertilizer from the nitrates present in the cultures receiving nitrogen in addition. As already noted in the graphs, the greatest difference in the nitrates produced where dolomitic limestone had and had not been added in the fertilizer was where the rate of fertilization was high and where the soil was the most acid. Thus, even after 122 days, only about one-fourth as much of the nitrogen added to soil 745 in the acid-forming fertilizer had nitrified as where the potentially neutral fertilizer was used; whereas with the more acid Dekalb silt loam (soil 744), less than one-fifteenth as much of the nitrogen was nitrified where the acid-forming fertilizer was used as where dolomitic limestone had been added to make the fertilizer potentially neutral. On less acid soils the difference in nitrification where acid-forming and where neutral fertilizers are added would, no doubt, be less.

TABLE 1.—*The effect of acid-forming and potentially neutral fertilizers on the nitrification of the ammonia in the fertilizer zone.**

Rate of fertilizer application, lbs. per acre†	Equivalent acidity of fertilizer (= lbs. $CaCO_3$ per ton)	Percentage of added ammonia nitrified			
		After 17 days	After 49 days	After 81 days	After 122 days
		Soil 745			
500	500	13.8	23.0	63.6	72.7
	0	28.4	77.8	92.2	96.4
2,000	500	1.2	5.2	12.0	12.1
	0	1.9	19.4	45.1	52.5
		Soil 744			
			After 45 days	After 104 days	After 134 days
2,000	500	—	0	0.5	2.3
	0	—	3.3	10.0	35.2

*6-8-6 fertilizer.
†On the basis of fertilizer zone. If it is assumed that the fertilizer zone represents 1/10 to 1/20 of the acre 6⅔ inches, the actual rates per acre would be 1/10 to 1/20 these amounts.

This important difference between the effects of acid-forming and potentially neutral fertilizers when applied to acid soils under certain conditions may be of considerable practical interest, for it has been

shown by Tiedjens (10) and others (1, 2, 4, 11) that at low pH values and with some crops nitrate nitrogen is more readily utilized by plants than is ammonium nitrogen. Thus, the use of non-acid-forming fertilizers on very acid soils may, by promoting nitrification of the ammonia, cause the nitrogen of the fertilizer to be more available to plants.

pH in the soil-fertilizer zone after various intervals.—The pH values of the soil in the soil-fertilizer zone after various intervals are shown

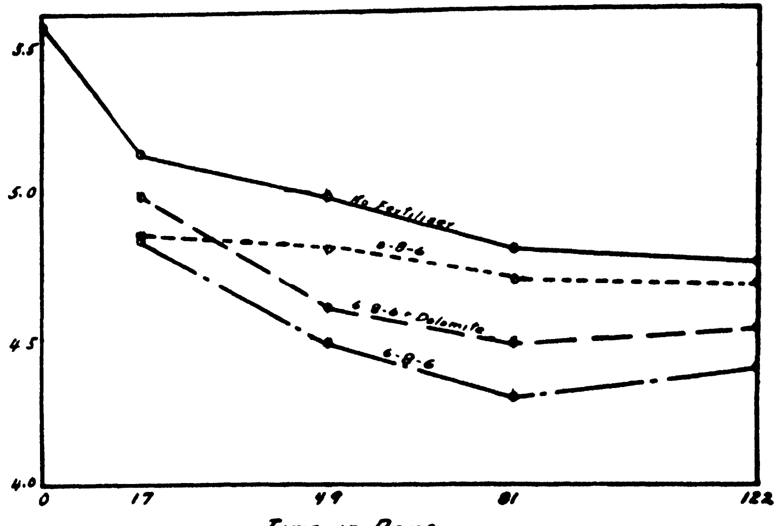

FIG. 4.—The pH of soil in fertilizer zone after various intervals; soil 745, Dekalb loam; low rate of fertilization.

in Figs. 4 and 5 for soil 745, and in Fig. 6 for soil 744. With the low rate of fertilizer application it will be seen from Fig. 4 that there was a rather rapid decrease in pH even where no fertilizer had been added. This is explained by the fact that the soil was removed from a sod area, and consequently the decomposition of some of the organic matter present and the production of nitrates (Fig. 1) took place rather rapidly. As would be expected, the cultures receiving the 0–8–6 fertilizer were lower in pH than the untreated ones, since an increase in salt concentration results in a temporary increase in hydrogen-ion concentration. The cultures receiving the 0–8–6 fertilizer, therefore, must be used as a standard in studying the effect of the complete fertilizer that is acid-forming and that which is potentially neutral. It will be noted that with the low rate of fertilization (Fig. 4) the complete fertilizer without dolomitic limestone caused a considerable increase in the acidity of the soil. The cultures which received the fertilizer containing dolomitic limestone had a slightly higher pH than those receiving the fertilizer without dolomite, but a lower pH than those receiving the 0–8–6 fertilizer. No doubt one of the reasons for the latter fact is that the dolomitic limestone did not decompose rapidly enough in this period of time to neutralize all the acidity formed from the rapid nitrification of the ammonia in the fertilizer.

In Fig. 5 are shown the data with the same soil but with a rate of fertilizer application four times as great. As was the case with the low rate of application series, the pH value of the soils receiving the 0–8–6

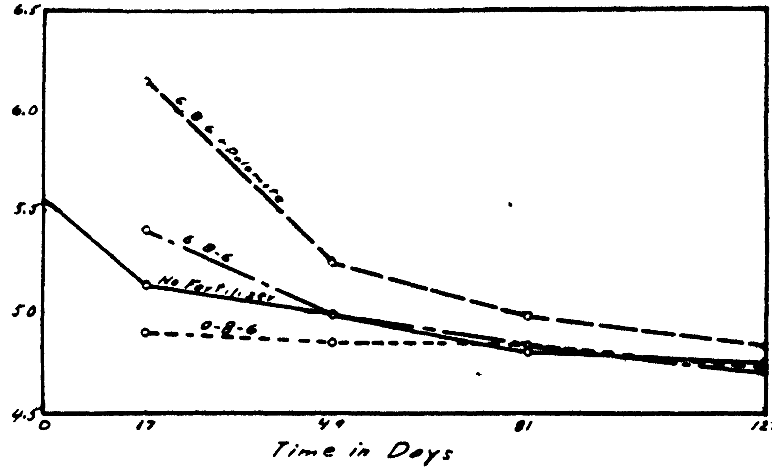

FIG. 5.—The pH of soil in fertilizer zone after various intervals; soil 745, Dekalb loam; high rate of fertilization.

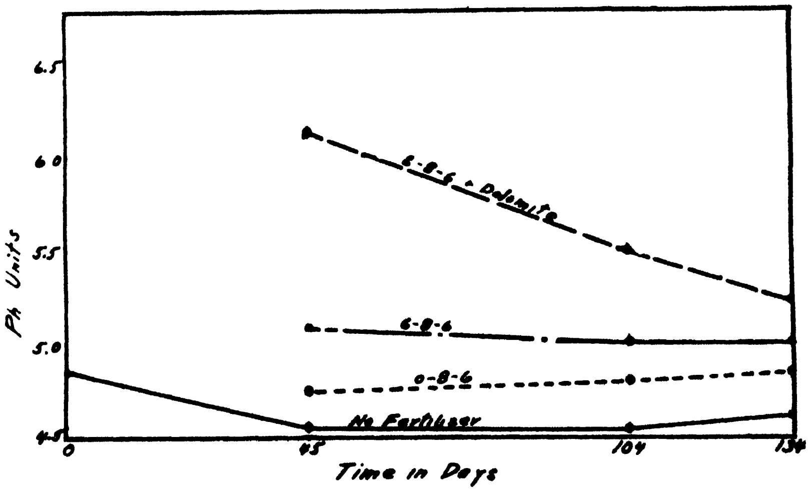

FIG. 6.—The pH of soil in fertilizer zone after various intervals; soil 744, Dekalb silt loam; high rate of fertilization.

fertilizer and the "no fertilizer" treatment decreased rapidly during the first 17 days. Thereafter, the decrease was slower and in proportion to the decrease in nitrification (Fig. 2). With the complete fertilizer containing no dolomitic limestone, it is interesting to note that at the time of the first sampling the pH value of the soil was considerably higher than where the 0–8–6 fertilizer was used. This is no doubt explained by the fact that one-third of the nitrogen was derived from

urea and that before nitrification had taken place ammonium carbonate was being formed from the decomposition of urea. As shown in Fig. 2, nitrification was very slow where the acid-forming fertilizer was used. The potentially neutral fertilizer containing dolomitic limestone caused a rapid increase in pH, as shown by the data obtained after 17 days. This is due partly to the dolomitic limestone and partly to the temporary effect of the urea, previously described. After 17 days the pH value decreased rapidly. This is to be expected from the fact previously noted (Fig. 2) that there was a rapid increase in nitrification after this period.

At first thought it seems surprising that the dolomitic limestone supplement did not show a greater basic effect on the soil after the 49-day period. This is readily explained, however, by the fact that nitrification is an acidifying process and that the amount of nitrates produced was much greater where the neutral than where the acid-forming fertilizer was used. Thus, on the basis of the soil in the fertilizer zone it is found by calculation that approximately 2,900 pounds of calcium carbonate would be required per 2,000,000 pounds of soil to neutralize the acidity produced by the greater amount of nitrogen nitrified in the cultures receiving the dolomitic limestone-fertilizer mixture than in those receiving the sand-fertilizer mixture. This means that practically three-fifths of the limestone added was used in correcting the acidity produced by this greater nitrate formation. As the ammonia from the acid-forming fertilizer becomes nitrified to the same extent as that from the fertilizer containing dolomitic limestone, the difference in the pH values of the soils treated with the two fertilizers will naturally become greater. It must be emphasized also that the low pH values after 122 days as compared with those at the beginning of the experiment even where the dolomitic limestone had been used are due to the high salt concentration allowed to develop under the conditions of the experiment and to the fact that the equivalent acidity values given for the fertilizer are based on the presence of plant growth. These factors are discussed further on pages 637 to 640.

The data obtained with the more acid Dekalb silt loam soil are shown in Fig. 6. As with the other soil, there is found a close relationship between the pH changes and the rate of nitrification. With the 0–8–6 fertilizer, and also with the 6–8–6 fertilizer not containing dolomitic limestone, little nitrification took place, and as will be seen in Fig. 6, there was little change in pH from the 45th to the 134th day. The higher pH obtained with the acid-forming 6–8–6 fertilizer can be explained again by the formation of ammonium carbonate from urea and the fact that nitrification of the ammonium carbonate did not take place on account of the high salt concentration and the high acidity. With the 6–8–6 fertilizer containing dolomitic limestone there was found to be a rapid rise in pH at the time of the first sampling, and a steady decrease thereafter as nitrification proceeded rapidly.

Concentration of soluble magnesium in the soil-fertilizer zone.—The soluble magnesium contents of the soil for the various intervals after fertilization are shown in Figs. 7, 8, and 9. The data are given as p.p.m. on the dry-soil basis. It is apparent from the data that all

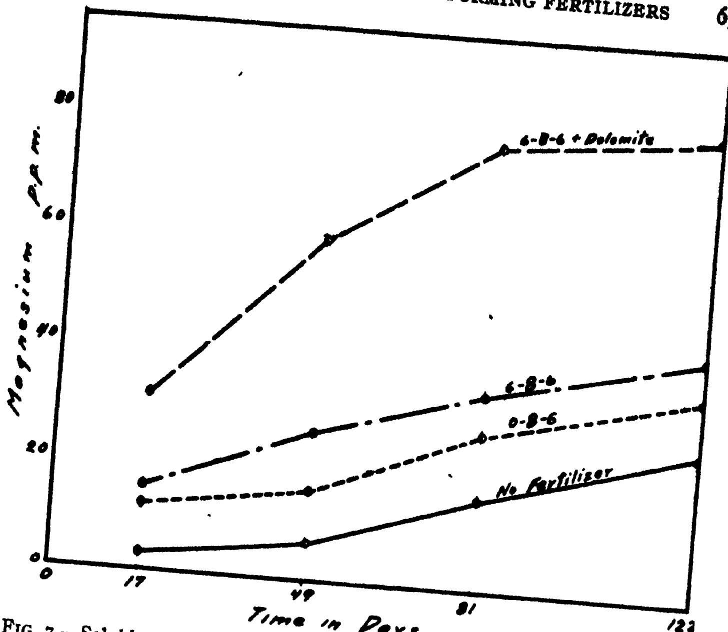

FIG. 7.—Soluble magnesium in fertilizer zone after various intervals; soil 745, Dekalb loam; low rate of fertilization.

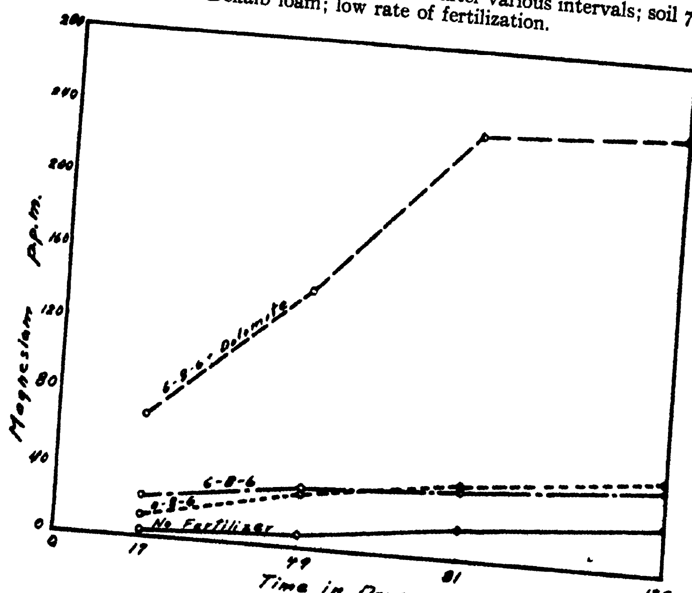

FIG. 8.—Soluble magnesium in fertilizer zone after various intervals; soil 745, Dekalb loam; high rate of fertilization.

fertilizers, even those to which no magnesium compounds were added, increased the water-soluble magnesium content of the soil. This is explained by the fact that the addition of soluble salts, such as potassium chloride and calcium sulfate, results in a liberation of bases from the exchange complex and thus tends to bring some magnesium into solution. The comparison of primary interest, however, is between the effects of the acid-forming fertilizer and the potentially neutral fertilizers containing dolomitic limestone. With the low rate of fertilization it will be noted from Fig. 7 that the concentration of water-soluble magnesium in the soil is about twice as high with the potentially neutral fertilizer as with the acid-forming fertilizer of similar analysis. The data in Fig. 8 show that with the high rate of fertilization on the same soil the dolomitic limestone in the fertilizer caused a three- to fivefold increase in the soluble magnesium content of the soil. Similar increases are shown in Fig. 9 for the Dekalb silt loam soil.

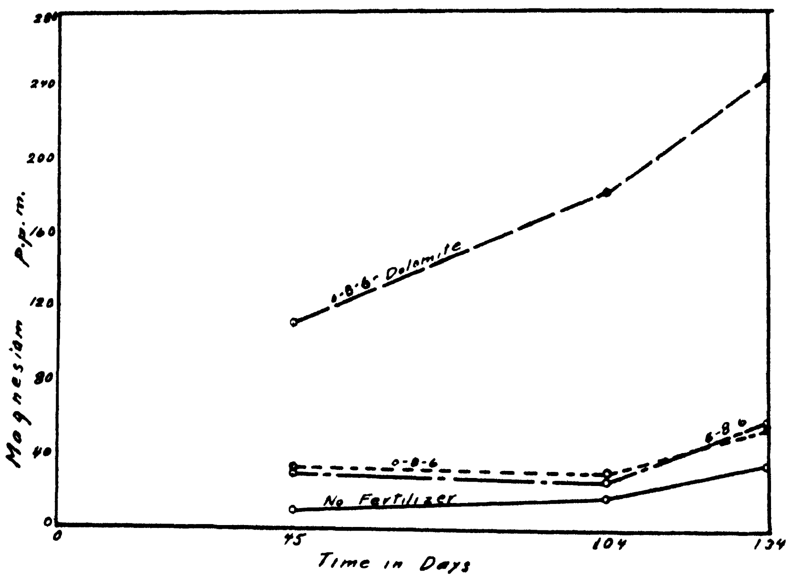

FIG. 9.—Soluble magnesium in fertilizer zone after various intervals; soil 744, Dekalb silt loam; high rate of fertilization.

The concentration of magnesium in the soil-fertilizer zone will be affected, of course, by the fineness of the dolomitic limestone. Data on this point for limestones of different degrees of fineness will be presented in a later paper (9).

EXPERIMENT II. CHANGES IN THE SOIL-FERTILIZER ZONE AND PLANT GROWTH RESPONSES FROM THE USE OF NEUTRAL FERTILIZERS

EXPERIMENTAL PROCEDURE

Nine soils obtained from West Virginia, South Carolina, and Alabama, and varying in pH from 4.60 to 5.40 and in texture from a loamy sand to silt loam,

were used in this study. Each soil was mixed thoroughly and definite amounts, varying among the different soils from 7,500 to 1,100 grams, were placed in 2-gallon glazed earthenware pots. Half of these pots in each series were fertilized with an acid-forming fertilizer and the remainder with a similar fertilizer, except that it contained dolomitic limestone to make it non-acid-forming. The analysis of the fertilizers and their equivalent acidity values are given in Table 2. Seventy-five per cent of the nitrogen in the 6–8–6 fertilizer came from ammonium sulfate, 16.67% from sodium nitrate, and 8.33% from Ammo-phos; whereas in the 4–6–6 fertilizer 62.5% came from ammonium sulfate, 25% from sodium nitrate, and 12.5% from ammonium phosphate. In the 4–10–6 fertilizer, 75% of the nitrogen came from ammonium sulfate and 25% from ammonium phosphate. In all the above fertilizers, part of the phosphate came from ammonium phosphate and the remainder from superphosphate, and all the potassium came from muriate of potash.

Sand was used as a filler in the acid-forming and dolomitic limestone in the potentially neutral fertilizer. The limestone used in the neutral fertilizer analyzed 56.08% calcium carbonate and 43.64% magnesium carbonate. The mechanical analysis was as follows: All went through a 40-mesh sieve; 20% was held on the 60-mesh, 20% on the 80-mesh, 10% on the 100-mesh, and 50% was finer than 100-mesh.

The fertilizer in each case was mixed with one-tenth of the total amount of soil in the pot and placed in the form of a cylindrical column in the middle of the pot by means of a metal cylinder open at both ends. The untreated soil then was placed around the metal cylinder and packed lightly. A circular metal collar, painted with asphaltum paint, 1½ inches in height and slightly larger than the cylinder, was placed over the end of the cylinder and imbedded about ½ inch in the soil, and the metal cylinder then was removed. Sudan grass was planted in the unfertilized soil in a circular arrangement about 1 inch from the collar. Distilled water was added as needed to bring the soil up to approximately optimum moisture conditions. All treatments were either in duplicate or triplicate.

Soil samples were removed from within the soil-fertilizer zone 3 weeks after fertilization and determinations made on the water extract for pH, nitrates, magnesium, calcium, and phosphate. The remainder of each soil sample taken at this time was kept in a beaker at approximately optimum moisture conditions for another 3 weeks, after which the concentration of water-soluble phosphate again was determined. At the time of harvesting, soil samples were taken from the soil-fertilizer zone and also from the unfertilized soil and pH determinations made. Phosphates were determined by the colorimetric method as described by Parker and Fudge (5), calcium by the standard method, and the other determinations by the methods used in Experiment I.

EXPERIMENTAL RESULTS

Nitrates and pH in the soil-fertilizer zone.—In Table 2 data are presented showing the effect of acid-forming and potentially neutral fertilizers containing dolomitic limestone on nitrate accumulation 3 weeks after fertilization and on the pH values of the nine soils after 3 weeks and at harvest time. It is seen that even after only 3 weeks all the soils studied showed a higher nitrate accumulation with the neutral than with the acid-forming fertilizer, although in some cases the increase was very small. If soil 755, for which no nitrate data are

TABLE 2.—*The effect of acid-forming and of neutral fertilizers on the nitrate concentration and the pH of the soil in the fertilizer zone.*

Soil No.	Soil type	Fertilizer treatment*	Nitrate-nitrogen, p.p.m.			pH of soil						
			At beginning	After 3 weeks		At beginning of experiment	After 3 weeks		At harvest		Outside soil-fertilizer zone at harvest
				Acid-forming fertilizer	Neutral fertilizer		Acid-forming fertilizer	Neutral fertilizer	Acid-forming fertilizer	Neutral fertilizer	
746	Dekalb silt loam	10,000 lbs. 4–8–6	11.2	61.1	91.2	5.40	5.20	5.70	4.85	5.33	5.33
747	Dekalb silt loam	10,000 lbs. 4–8–6	19.8	62.0	64.8	4.75	4.70	5.20	4.53	4.93	4.70
748	Dekalb fine sandy loam	10,000 lbs. 4–8–6	0	20.5	39.3	4.73	4.80	5.30	4.83	4.85	4.50
749	Wheeling fine sandy loam	10,000 lbs. 4–8–6	23.6	63.8	89.6	5.05	4.95	5.55	4.68	5.03	4.95
751	Norfolk loamy sand (S. C.)	8,000 lbs. 4–6–6	0	46.9	51.8	5.10	5.00	5.60	N.D.	N.D.	N.D.
753	Monongahela fine sandy loam	8,000 lbs. 4–10–6	0	30.4	43.5	4.95	4.75	5.03	4.73	4.88	4.80
754	Pope loam	8,000 lbs. 4–10–6	0	18.8	30.5	5.40	4.98	5.10	4.68	4.92	5.13
755	Holston silt loam	8,000 lbs. 4–10–6	N.D.†	34.4	40.0	4.80	4.53	4.83	4.48	4.68	4.68
756	Norfolk sandy loam (Ala.)	8,000 lbs. 4–10–6	0	9.7	16.8	5.40	5.00	5.30	4.85	5.07	5.10

*Equivalent acidity values for acid-forming fertilizers:
6–8–6 = 500 lbs. per ton
4–6–6 = 285 lbs. per ton
4–10–6 = 428 lbs. per ton
Rate of fertilization given is on the basis of the fertilized zone and is expressed as pounds per 2,000,000 pounds of soil.
†N.D. = Not determined.

available at the beginning of the experiment, is excluded, it is found that approximately 44% more ammonia was nitrified with a neutral than with an acid-forming fertilizer.

As might be expected, the use of a potentially neutral fertilizer as compared with an acid-forming one increased the pH of the soil in the fertilizer zone in all cases after 3 weeks' time and on all but one soil (No. 748) at harvest. In the latter soil the acid-forming fertilizer did not cause an increase in acidity. This no doubt can be explained by two facts; first, nitrification of the added ammonia was very slow as a result of the combination of high acidity and high salt concentration; and second, plants made practically no growth where the acid-forming fertilizer was used. As the ammonia supplied by the fertilizer gradually nitrifies, the pH value no doubt will be decreased. On the other hand, considerable nitrification and plant growth resulted where the potentially neutral fertilizer was used. The low pH value of the soil on the outside of the fertilizer zone at harvest probably is due to nitrification of the soil organic matter, for it has been found in other experiments with this soil that considerable nitrification takes place in the absence of a high salt concentration. It is interesting to note the similarity in pH of the soil inside the soil-fertilizer zone at harvest where a potentially neutral fertilizer was used and the pH of the unfertilized soil. Of the eight soils reported, five show approximately the same pH values, while three show some differences.

Concentration of phosphate, magnesium, and calcium in the soil-fertilizer zone.—The effect of acid-forming and potentially neutral fertilizers containing dolomitic limestone on the concentration of water-soluble phosphate in the soil-fertilizer zone 3 and 6 weeks after fertilization is given in Table 3. It is interesting to note in comparing the results obtained with a neutral and an acid-forming fertilizer that the use of the former caused an increase in concentration of phosphate in the soil-fertilizer zone on four of the nine soils studied. Although in some cases the differences were small, it is observed that they still persisted even 6 weeks after fertilization. This shows that with soils that are very acid or those that have a high fixing power for phosphorus, the use of a potentially neutral instead of an acid-forming fertilizer may increase the concentration of water-soluble phosphate in the soil-fertilizer zone.

The concentration of soluble magnesium in the soil-fertilizer zone 3 weeks after fertilization is also given in Table 3. The results show, as was brought out in Experiment I, that the addition of dolomitic limestone to make the fertilizer non-acid-forming caused a considerable increase in concentration of water-soluble magnesium in the soil-fertilizer zone. Even after only 3 weeks' time, on two of the soils studied (Nos. 746 and 748), the concentration of soluble magnesium was more than trebled as a result of using a potentially neutral fertilizer containing dolomitic limestone. It is interesting to compare the concentration of soluble magnesium in the soil-fertilizer zone on the loamy sand No. 751 where a neutral and where an acid-forming fertilizer was used. As can be seen, the use of the former more than doubled the concentration of magnesium even though the acid-

TABLE 3.—*The effect of acid-forming and neutral fertilizers on the water soluble PO_4, magnesium, and calcium in the soil of the fertilized zone after various intervals of time.*

Soil No.	Soil type	pH of untreated soil	Fertilizer treatment*	Water-soluble PO_4, p.p.m.				Water-soluble Mg, p.p.m.		Water-soluble Ca, p.p.m.	
				After 3 weeks		After 6 weeks		After 3 weeks		At harvest	
				With acid-forming fertilizer	With neutral fertilizer	With acid-forming fertilizer	With neutral fertilizer	With acid-forming fertilizer	With neutral fertilizer	With acid-forming fertilizer	With neutral fertilizer
746	Dekalb silt loam	5.40	10,000 lbs. 6–8–6	5.50	7.00	3.35	4.25	21.9	70.8	547	795
747	Dekalb silt loam	4.75	10,000 lbs. 6–8–6	4.63	5.13	2.65	3.25	39.4	71.7	413	811
748	Dekalb fine sandy loam	4.73	10,000 lbs. 6–8–6	1.76	1.94	0.82	1.22	26.4	90.3	327	724
749	Wheeling fine sandy loam	5.05	10,000 lbs. 6–8–6	7.50	7.50	5.60	5.90	53.4	108.5	723	804
751	Norfolk loamy sand (S. C.)	5.10	8,000 lbs. 4–6–6	20.35	25.65	15.15	19.70	18.6	43.7	N.D.	N.D.†
753	Monongahela fine sandy loam	4.95	8,000 lbs. 4–10–6	9.53	9.38	6.00	6.25	41.0	67.2	126	373
754	Pope loam	5.40	8,000 lbs. 4–10–6	11.75	10.90	6.38	6.63	52.3	75.2	385	449
755	Holston silt loam	4.80	8,000 lbs. 4–10–6	3.38	3.81	2.50	2.69	63.9	79.3	178	305
756	Norfolk sandy loam (Ala.)	5.40	8,000 lbs. 4–10–6	20.60	20.70	15.80	15.70	29.0	46.3	138	158

*Equivalent acidity values for acid-forming fertilizers:
6–8–6 = 500 lbs. per ton
4–6–6 = 285 lbs. per ton
4–10–6 = 428 lbs. per ton
Rate of fertilization given is on the basis of the fertilized zone and is expressed as pounds per 2,000,000 pounds soil

forming fertilizer had an equivalent acidity of only 285 pounds calcium carbonate per ton.

In the last two columns of Table 3 are given the concentration of water-soluble calcium in the soil after harvesting the crop. In all cases the calcium is much higher with the neutral than with the acid-forming fertilizer. Determinations of calcium were also made on soil samples removed 3 weeks after fertilization. The concentrations present at this time were very high and showed little differences with the two types of fertilizers. This is what might be expected since large amounts of calcium sulfate were applied in the fertilizer.

Plant growth and yield data.—The yields of Sudan grass in grams of dry weight per pot are given in Table 4. Results obtained from eight different soils show that the potentially neutral fertilizers produced higher yields than did the acid-forming fertilizer on four of the soils and had little effect on the others. These increases in yield were obtained, with one exception, on the four most acid soils and the greatest increase was obtained on the most acid soil (No. 748). It should be mentioned that during the early stages of growth, some of the other soils produced poorer growth where the acid-forming fertilizers were used, but in these cases the injurious effect of acidity was overcome largely, before harvest. This was especially true on soils 747 and 756. The yield from one pot of soil 754, where an acid-forming fertilizer was used, is considerably higher than its companion pots, but no explanation is available for this behavior. In Fig. 10 is shown the effect of an acid-forming and potentially neutral fertilizer containing dolomitic limestone on the growth of Sudan grass in the greenhouse for 39 days on soils 753 and 755.

GENERAL DISCUSSION

While, as emphasized previously, the main value of neutral fertilizers in general is the prevention of a harmful increase in soil acidity over a period of years, their advantage over acid-forming fertilizers may become evident during the first year if the soil already is very acid, or if deficient in available magnesium. In the greenhouse experiments reported in this paper the beneficial effect of neutral over acid-forming fertilizers probably was due to differences in acidity found in the soil-fertilizer zone. These differences need not be large, of course, if the pH value of the soil is near the critical point for the plant being grown.

The pH values obtained in experiment I are of interest primarily in illustrating the close correlation existing between nitrification and the development of acidity in uncropped soils. Where nitrification of the ammonia of the acid-forming fertilizer was inhibited because of the high soil acidity already existing and to the high salt concentration, there was, as would be expected, little, if any, increase in acidity. The true effect of the acid-forming fertilizer on soil acidity, therefore, was not developed during the duration of the experiment. Moreover, this experiment illustrates the effect of salt concentration on the pH of soils. Thus, the pH values obtained with the potentially neutral fertilizers were considerably lower than those of the original soils. It should be recognized, however, that this effect is not permanent but

is due to a slight exchange of the cation of the neutral salts (calcium sulfate, potassium chloride, etc.) with the hydrogen in the soil-exchange complex. Where plants were growing on the soils as in ex-

TABLE 4.—*The effect of acid-forming and neutral fertilizers on the yield of Sudan grass in greenhouse experiments.*

Soil No	Soil type	pH of untreated soil	Fertilizer treatment*	Yield of Sudan grass, grams dry weight per pot			
				With acid-forming fertilizer		With neutral fertilizer	
				Individual	Average	Individual	Average
746	Dekalb silt loam	5 40	10,000 lbs. 6–8–6	33.3 38.8	36.1	32.6 36.5	34.6
747	Dekalb silt loam	4 75	10,000 lbs 6–8–6	35.7 34.6	35.2	36.0 38.0	37.0
748	Dekalb fine sandy loam	4.73	10,000 lbs. 6–8–6	0.5 0 7	0.6	12.3 8.4	10.4
749	Wheeling fine sandy loam	5 05	10,000 lbs. 6–8–6	29 2 31.7	30.5	36.7 34.0	35.4
751	Norfolk loamy sand (S. C.)	5 10	8,000 lbs. 4–6–6	—†	—	—	—
753	Monongahela fine sandy loam	4 95	8,000 lbs. 4–10–6	15.5 17.7 14.7	16.0	25.1 26.9 25.5	25.8
754	Pope loam	5 40	8,000 lbs. 4–10–6	23.2 34.0 24.9	27.4	27.3 28.6 27.6	27.7
755	Holston silt loam	4.80	8,000 lbs. 4–10–6	16.9 21.7 18.7	19.1	23.7 25.2 27.4	25.4
756	Norfolk sandy loam (Ala.)	5.40	8,000 lbs. 4–10–6	16.6 16.2 14.3	15.7	15.9 17.4 19.8	17.7

*Equivalent acidity values for acid-forming fertilizers:
6–8–6 = 500 lbs. per ton
4–6–6 = 285 lbs per ton
4–10–6 = 428 lbs per ton
Rate is on basis of fertilizer zone. If it is assumed that the fertilizer zone represents 1/10 to 1/20 of the acre 6⅔ inches, the actual rates per acre would be 1/10 to 1/20 these amounts.
†Sudan grass was not grown on this soil.

periment II and where there was some opportunity for the salts to diffuse from the heavily fertilized soil zone, the potentially neutral fertilizer maintained the soil at about the original pH value.

It should be emphasized also that the acidity developed by ammonium fertilizers in uncropped soils is higher than where crops are growing. Thus, it has been shown that where plants are growing one-half of the nitrogen applied in fertilizers, in general, can be considered

FIG 10 —Growth of Sudan grass on Monongahela fine sandy loam (No 753) and Holston silt loam (No 755) with an acid-forming (left) and a neutral (right) fertilizer

acid-forming (6, 7). Where plants are not growing, however, and where complete nitrification takes place, the nitrogen should exert its full acid effect on the soil. The non-acid-forming fertilizers used in experiment I, therefore, would not be expected to maintain the pH at its original value even if salt concentration had not been a factor.

The foregoing discussion emphasizes some of the factors that must be considered in evaluating the permanent effect of fertilizers on soil acidity. Not only may non-acid-forming fertilizers cause a temporary increase in acidity as a result of high salt concentration or of other factors, but it also has been shown in this investigation that acid-forming fertilizers may temporarily decrease the acidity of the soil in the heavily fertilized soil zone. Thus, the use of urea in a mixed fertilizer caused a temporary increase in the pH of the soil fertilizer zone. These temporary effects of fertilizers on soil acidity may be important under certain conditions, but they should be distinguished clearly from the permanent effects, which are considered the criteria of whether or not a fertilizer is acid-forming.

SUMMARY

In this investigation studies were made on soils in the laboratory and in the greenhouse regarding the comparative effects of acid-forming and potentially neutral fertilizers containing dolomitic limestone supplements on plant growth and on the following chemical and biological changes in the soil-fertilizer zone: (a) Nitrification of added ammonia, (b) pH values, and (c) concentration of water-soluble magnesium, calcium, and phosphate. Eleven different soils obtained from West Virginia, South Carolina, and Alabama and varying in pH from 4.73 to 5.40 were used in the study.

The results show that on the relatively acid soils studied potentially neutral fertilizers containing dolomitic limestone supplements promoted nitrification in the soil-fertilizer zone to a much greater extent than did acid-forming fertilizers. This was true especially on the more acid soils and where the rate of fertilization was high. Thus, in some cases, 4 to 15 times as high a percentage of the added ammonia was nitrified where the potentially neutral fertilizer was used.

The pH of the soil in the fertilizer zone is substantially higher where potentially neutral than where acid-forming fertilizers are used. This is true particularly where the high rate of fertilization was used and during the first few weeks after fertilization. Thereafter, as the differences between the amount of nitrates produced with the two types of fertilizers increased, the pH differences decreased.

Urea in a complete fertilizer tended to cause a temporary increase in the pH of the soil in the fertilizer zone, apparently as the result of the formation of ammonium carbonate. With the high rate of fertilizer application and on a very acid soil, a small increase in pH was found to persist for several months. This is explained by the fact that under these conditions nitrification of the ammonium carbonate was slow.

Mixed fertilizers containing dolomitic limestone to make them non-acid-forming caused a marked increase in the concentration of water-soluble magnesium in the soil-fertilizer zone. With a low rate of fertilization the concentration of magnesium in the medium-acid Dekalb

loam was more than doubled by the use of dolomitic limestone in the fertilizer mixture. Where a high rate of fertilization was used, the increase was three to five times as great. Similar increases were obtained with other soils.

The use of a potentially neutral rather than an acid-forming fertilizer caused a definite increase in concentration of water-soluble phosphate in the soil-fertilizer zone after 3 and 6 weeks' time on four of the nine soils studied. The remaining soils gave no significant differences in concentration of soluble phosphate.

Yields of Sudan grass from eight different soils show that a potentially neutral fertilizer produced a higher yield than did the acid-forming fertilizer on four of the soils and had little effect on the others. In general, the greatest differences in yields obtained with the two types of fertilizers were on the most acid soils.

It is emphasized that the temporary effect of fertilizers on soil acidity should be distinguished clearly from their permanent effects.

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VITALITY AND GERMINATION OF CRIMSON CLOVER SEED AS AFFECTED BY SWELLING AND SPROUTING AND SUBSEQUENT DRYING[1]

ROLAND MCKEE[2]

ALTHOUGH germination of seed and subsequent survival are influenced by weather and seedbed conditions, the relative difference in ease or assurance with which a crop makes a stand can not be attributed to these factors alone. The characteristics which make crops inherently different are influencing factors and must be given consideration in any study of the subject.

In vernalization experiments with crimson-clover (unpublished), it has been noted that in cases where the seed has germinated sufficiently to have the radicle protruding and the seed subsequently dried, poor stands and growth result. In order to determine more definitely the effect of swelling and sprouting and subsequent drying on the vitality and germination, the experiments herein reported were undertaken. These were carried out in an ordinary laboratory room at a temperature of 20° to 22°C.

Hulled crimson clover seed was germinated for varying intervals and then dried at ordinary room temperature. After drying for from 8 to 10 days the seed was again started into growth, as indicated in the tabulated data (Table 1). The seed moistened for 22 hours fully swelled but showed no radicle elongating. The radicles began to appear in 27 hours, however, and were 10 mm long in 76 hours. It will be noted from the tabulation that seed that had the radicle showing when dried was seriously injured, while seed in which the radicle had not yet appeared was hurt but little. Longer periods of drying than indicated in the table gave similar results. When the time of drying slightly sprouted seed was varied from 52 to 192 hours, the drying in all cases injured the seed, the amount of injury increasing with the length of time.

TABLE 1.—*Laboratory test with crimson clover seed.*

Treatment No.	Preliminary treatment Jan. 22 to Jan. 30			Laboratory germination test in blotters Jan. 30 to Feb. 8		
	No. hours in contact with H_2O	Length of radicle in mm	No. hours dried after moistening	Per cent cotyledons greening	Per cent good plants	Vigor and height of plants
1	22	0	169	90	85	Strong, 4 cm
2	27	1	164	90	45	Medium, 2 cm
3	45	5	146	25	5	Weak, 1 cm
4	69	10	122	15	5	Weak, 1 cm
5	76	10	115	15	0	None

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication May 10, 1935.

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To determine further the effect of continuing the swelled period for various lengths of time without the radicle appearing, one lot of seed was moistened for 1 hour and then dried, while another was kept moist 42 hours before drying. These were compared with a check lot of seed that had not been moistened.

The lot that had been in contact with moisture 42 hours, upon remoistening, germinated first and was appreciably ahead of the 1-hour lot. The check was slowest in starting and was appreciably behind the 1-hour lot. The percentage of germination of the various lots was 77 for the 42-hour lot, 73 for the 1-hour lot, and 71 for the check. In other tests with this same general lot of seed, the checks have germinated as much as 80% with the average being about 75%. From this test, it is indicated that swelling and subsequent drying for several days, if the radicle has not appeared, does not affect the vitality of the seed, and that when it is remoistened, growth starts quicker than in untreated seed.

In connection with studies (unpublished) on arrested growth in the germinating or seedling stage of certain other crops, it has been observed that the ability of seedlings to recover after once started into active growth and subsequently dried, varies widely. Many grasses recover readily after being sprouted with the radicle and plumule both well started into growth and subsequently thoroughly air-dried. The same is true of some legumes with hypogeous cotyledons, but apparently not true or only partially so with legumes with epigeous cotyledons.

These data and observations help to explain why crimson clover is an undependable crop in obtaining stands, as indicated by the general experience of farmers.

THE RELATION BETWEEN EFFECTIVE RAINFALL AND TOTAL CALCIUM AND PHOSPHORUS IN ALFALFA AND PRAIRIE HAY[1]

HARLEY A. DANIEL AND HORACE J. HARPER[2]

ALTHOUGH a considerable amount of research has been conducted on the mineral content of forage, only a few correlations have been made between the effective seasonal rainfall and the total calcium and phosphorus in plants. Orr (14)[3] reported data on oat hay which was low in calcium and high in phosphorus during a wet season. Ferguson (9), and Woodman, Norman, and French (19) found that a prolonged drouth caused a decrease in the percentages of nitrogen and phosphorus and an increase in the calcium content of pasture plants. McCreay (13), Archibald, Nelson, and Bennett (2), and Eckles, Becker, Berton, and Palmer (7) found that the phosphorus content of forage plants varied directly with rainfall.

The effect of maturity on the mineral content of plants has been studied by several investigators (1, 3, 4, 5, 8, 10, 16). Results have been secured which show that the total phosphorus and nitrogen are highest in young plants and decrease as the plants mature; whereas, the percentage of total calcium increases during the earlier stages of plant development, reaching a maximum in early summer, and then decreases slowly as growth continues. Other factors which may affect the mineral content of plants are soil conditions (11, 12), kind of plant (6), and fertilizer application (15, 17, 18).

Due to the wide variation in climatic conditions which occur in Oklahoma and to the intermittent occurrence of evidence indicating that mineral deficiencies frequently appear in different types of livestock, a series of experiments have been conducted to determine the effect of rainfall and fertilization on the mineral content of native grass and alfalfa hay.

EXPERIMENTAL PROCEDURE

In 1929 an experiment was started at the Oklahoma Agricultural Experiment Station to study the effect of the addition of nitrogen, phosphorus, and potassium fertilizers on the growth and composition of native grass. An area of uniform soil which was covered with vegetation composed chiefly of little blue stem (*Andropogon scoparius*) was divided into 30 plats and the different fertilizer treatments were broadcasted annually on the surface of the soil about the first of April. Every third plat received no treatment in order to study differences in soil variation and the effect of different fertilizers on growth and yield. Composite samples of grass were obtained for analysis at the time the hay was harvested. The samples were collected each year from 1929 to 1933.

The soil on which this experiment was located is Kirkland loam. The surface soil is brown in color, and is underlaid by a dark red compact clay subsoil. It is

[1]Contribution from the Department of Agronomy, Oklahoma Agricultural Experiment Station, Stillwater, Okla. Received for publication May 13, 1935.
[2]Assistant Agronomist and Professor of Soils, respectively.
[3]Figures in parenthesis refer to "Literature Cited," p. 651.

slightly acid, but the acidity decreases with depth, a neutral reaction usually being encountered at 12 to 18 inches below the surface.

Another experiment was started in 1931 on the Perkins farm of the Oklahoma Agricultural Experiment Station to study the effect of different phosphate fertilizers, complete fertilizers prepared from high and low analysis material, and farm manure used alone and supplemented with phosphorus and potassium on the growth and composition of alfalfa hay. All fertilizers were cultivated into the seedbed in the spring of 1931 before the alfalfa was planted. In 1932 and 1933 the fertilizers which were to be applied annually were broadcasted on the surface of the soil about March 15. No crop was harvested the first season. Three cuttings of alfalfa hay were obtained in 1932 and in 1933. At each cutting, samples of hay were secured from 68 plats. Since each fertilizer treatment was repeated four times in this experiment, all samples from plats receiving the same treatment were combined into one composite sample for analysis, making a total of 17 samples for analyses.

The soil on which this experiment was located is a brown sandy loam and is very similar to the Bates series. The surface soil is underlaid by a friable sandy clay which does not restrict the movement of soil moisture or root development.

All of the native grass and alfalfa hay was dried at 105° C, and analyzed for total calcium and phosphorus by official methods recommended by the Association of Official Agricultural Chemists.

RELATION BETWEEN TOTAL ANNUAL, TOTAL SEASONAL, EFFECTIVE ANNUAL, AND EFFECTIVE SEASONAL RAINFALL

An exact comparison of the variation in quantity of plant food in forage as affected by rainfall is not easy to make since some rains are small and scarcely moisten the surface of the soil, while other rains may be large and a portion may be lost either as gravitational water or by runoff when torrential rainfall occurs. Under the climatic conditions which prevail in this area much of the moisture which falls during the winter when plants are dormant may be lost by evaporation since a low humidity occurs during a considerable portion of this period.

In order to study the relation between rainfall and the calcium and phosphorus content of prairie grass and alfalfa, some consideration must be given to the nature of the rains occurring during the period of plant development. In order to obtain data on the relative differences between annual and seasonal rainfall, results secured at Stillwater, Okla., for the 5-year period from 1929 to 1933, inclusive, are shown in Fig. 1. Rains of less than 0.5 inch were classified as ineffective since the major portion of such showers are lost by evaporation. Total rainfall in excess of 2 inches for each rain was also classified as ineffective, since a large portion of torrential rainfall is lost by runoff.

Although the different rainfall curves are quite similar in character, a greater variation occurred in 1931 and 1932 as compared with data obtained during the other 3 years. Since only that moisture which penetrates into the soil and stays in the zone of root development will have any appreciable influence on plant growth, effective rainfall should correlate more closely with variations in plant composition and development than total rainfall. Whether

total effective rainfall should be selected as a basis for comparison instead of effective seasonal rainfall, may be determined from a study of factors which contribute to moisture losses from the soil. Lysim-

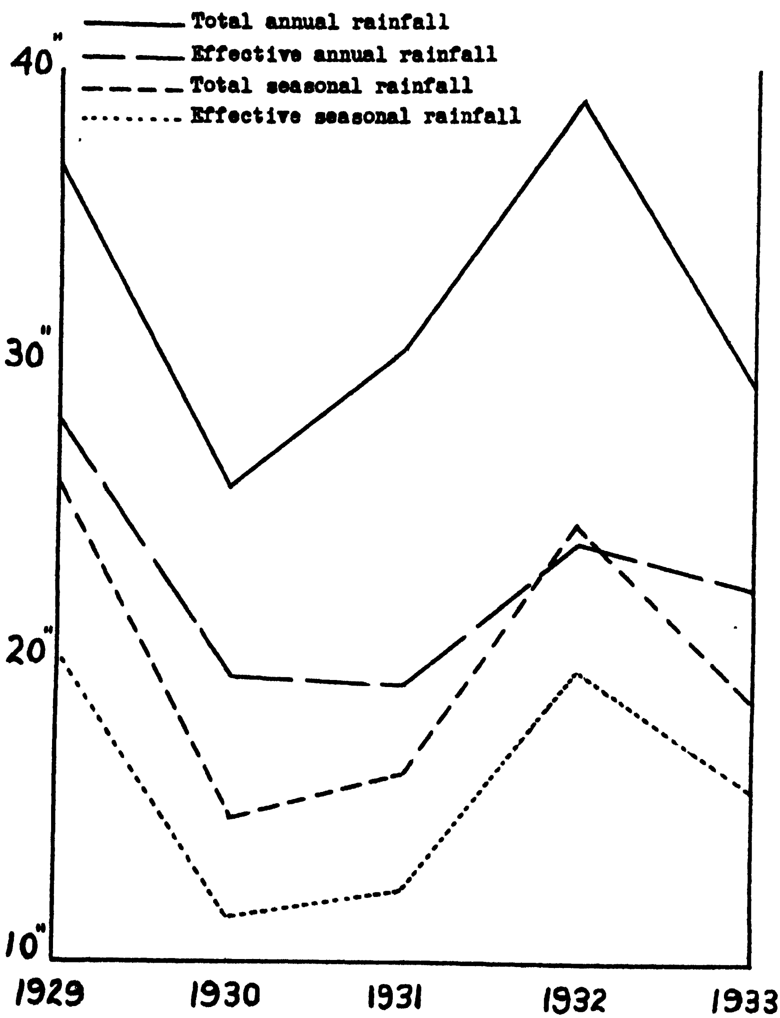

FIG. 1.—The relation between total annual, effective annual, total seasonal, and effective seasonal rainfall at Stillwater, Okla., from 1929 to 1933, inclusive.

eter studies at the Oklahoma Agricultural Experiment Station indicate that loss of water by percolation is negligible, due to the small amount of rainfall which occurs during the winter months; consequently, curves for effective seasonal rainfall and effective total rainfall should be similar in character. Effective rainfall which occurs

in late fall tends to disappear from the soil by evaporation and, although some of it may penetrate into the subsoil, it produces very little effect on the growth of native grass or alfalfa the following season unless supplemented by additional moisture derived from spring rains. As a result of these observations, comparisons have been made between effective seasonal rainfall and the calcium and phosphorus content of crops.

COMPARISON BETWEEN EFFECTIVE SEASONAL RAINFALL AND TOTAL CALCIUM AND PHOSPHORUS IN NATIVE PRAIRIE HAY AND ALFALFA

In order to study the relation between the effective seasonal rainfall and the mineral content of plants, rain that fell between January 1 and the time the prairie hay was harvested was compared with the total calcium and phosphorus in each crop. Since alfalfa produces more than one crop of hay each year, the calcium and phosphorus in the first cutting of alfalfa was compared with the effective rainfall which occurred between January 1 and the date on which the first crop of hay was harvested. Effective rains which fell between the different cutting dates were compared with the composition of forage produced during a similar period. Such a comparison introduces some error since a heavy rain may occur a few days before a crop is harvested and that moisture would be used by the following crop. It is quite possible that a better correlation between plant composition and rainfall would be obtained if more accurate information were obtained on the influence of the available moisture in the soil on plant composition. This phase of the problem is being studied under greenhouse conditions where soil moisture conditions can be carefully regulated.

The relationship between the effective seasonal rainfall and total calcium and phosphorus content of the unfertilized native prairie hay are given in Table 1. These data show that a considerable variation in total calcium and phosphorus occur between samples of forage produced on different plats which were treated in a similar manner; however, these variations are usually small when compared with seasonal fluctuations. Although fertilizer treatment slightly increased the phosphorus content of mature prairie hay, this variation was insignificant as compared with differences which occurred in the composition of forage produced during different seasons. The average total phosphorus content of prairie hay varied from 0.07% in 1930 to 0.138% in 1932. The average calcium content varied from 0.311% in 1929 to 0.610% in 1931.

The effective seasonal rainfall was high during the seasons of 1929 and 1932 and the average percentage of total calcium in the mature native grass was only 0.311 and 0.315% for 1929 and 1932, respectively. In 1930 and 1931, the effective seasonal rainfall was low and the prairie hay was very high in calcium, containing 0.475 and 0.610% for each year, respectively.

Data on the effective seasonal rainfall and the calcium and phosphorus content of the different cuttings of alfalfa are given in Table 2. The first crop of alfalfa in 1932 contained an average of 2.18%

TABLE 1 —*Data on the total calcium and phosphorus in unfertilized prairie hay and effective seasonal rainfall* *

Sample No	1929		1930		1931		1932		1933	
	Ca Per cent	P Per cent	Ca Per cent	P Per cent	Ca Per cent	P Per cent	Ca Per cent	P Per cent	Ca Per cent	P Per cent
1	0 419	0 098	0 367	0 064	0 480	0 079	0 399	0 098	0 318	0 086
2	0 301	0 094	0 476	0 066	0 745	0 095	0 418	0 090	0 453	0 133
3	0 288	0 069	0 485	0 064	0 650	0 070	0 362	0 176	0 365	0 144
4	0 288	0 083	0 596	0 088	0 715	0 090	0 340	0 105	0 365	0 081
5	0 314	0 083	0 342	0 082	0 560	0 093	0 312	0 141	0 398	0 134
6	0 262	0 096	0 485	0 066	0 577	0 092	0 272	0 119	0 435	0 113
7	0 270	0 079	0 668	0 066	0 731	0 080	0 286	0 185	0 360	0 150
8	0 275	0 069	0 432	0 096	0 585	0 082	0 274	0 121	0 313	0 097
9	0 367	0 095	0 452	0 069	0 535	0 089	0 272	0 148	—	—
10	0 328	0 079	0 445	0 067	0 520	0 089	0 235	0 095	0 428	0 085
Average	0 311	0 084	0 475	0 070	0 610	0 086	0 315	0 138	0 382	0 113
Effective seasonal rainfall inches	20 51		11 48		12 71		19 81		15 76	

**Andropogon scoparius* was the dominant type of vegetation growing on this area

TABLE 2 —*Data on the total calcium and phosphorus content of unfertilized alfalfa and effective seasonal rainfall*

Plat No	Percentage of calcium and phosphorus and date harvested											
	May 5 1932		July 7 1932		Aug 18 1932		May 27 1933		June 26, 1933		Sept 16, 1933	
	Ca	P	Ca	P	Ca	P	Ca	P	Ca	P	Ca	P
1	2 160	0 113	1 071	0 145	1 790	0 139	1 625	0 175	1 772	0 139	1 462	0 239
2	2 008	0 126	1 241	0 146	1 655	0 124	1 560	0 173	1 965	0 130	1 329	0 222
3	2 290	0 129	1 080	0 141	1 848	0 136	1 625	0 178	1 800	0 140	1 400	0 219
4	2 205	0 115	1 260	0 151	1 915	0 151	1 540	0 169	1 865	0 132	1 274	0 239
5	2 270	0 118	1 095	0 157	1 620	0 156	1 480	0 170	1 820	0 135	1 381	0 219
Average	2 186	0 120	1 149	0 148	1 766	0 141	1 566	0 173	1 844	0 135	1 369	0 228
Effective seasonal rainfall, inches	3 56		6 62		4 82		8 31		2 00		5.30	

of total calcium, while the second crop harvested from the same plats contained only 1.15% of total calcium. The first crop of alfalfa was harvested on May 25 and the effective rainfall from January 1 to May 25 was 3.56 inches, the majority of which fell during January and February. March and April were very dry and no effective rain occurred until May 3. The calcium content of this crop was high. The effective rainfall between the time the first crop was harvested and the date of the second cutting of hay was 6.52 inches. The calcium content of the second cutting of hay was very low. Although variations occur in the calcium content of the alfalfa obtained from different plats, these data indicate that during dry seasons the total calcium content of plants is higher than during periods when the soil contains an abundant supply of moisture for crop growth.

The average total phosphorus content of the alfalfa hay was 0.120% for the first cutting in 1932 and 0.228% for the third cutting in 1933. In 1932 the second crop of alfalfa was higher in total phosphorus than the first cutting, while in 1933 the second cutting of hay was much lower in total phosphorus than the first cutting.

Although the mathematical correlation between the actual amount of rain and the phosphorus in the alfalfa hay is not high, the figures show that the phosphorus content of alfalfa fluctuates with the rainfall; and that the calcium content of the hay is inversely proportional to the quantity of effective rainfall which occurs. The moisture requirement of crops is affected by the temperature and humidity of the atmosphere; consequently, total rainfall could influence plant growth quite differently depending upon whether high rainfall occurs during the spring or summer months. A greater variation in the calcium and phosphorus content of alfalfa occurred between the rainfall and the different cuttings of hay harvested in 1932 than in the hay harvested in 1933. During the season of 1932 the period of high rainfall was in May and June, while in 1933 the period of high rainfall was in March, April, and May.

Additional information which has been obtained from other studies made in this laboratory indicate that small grain and prairie hay are frequently low in phosphorus and calcium when grown on soils which are low in those elements; however, many soils which contain an abundant supply of plant food produce forage crops which are deficient in calcium or phosphorus due to the effect of seasonal conditions on plant development. This is especially important in semiarid regions where the plant food content of the soil is seldom a limiting factor in crop production.

A comparison of the effective seasonal rainfall and the average phosphorus and calcium content of fertilized and unfertilized mature prairie hay is shown in Fig. 2. A similar comparison for alfalfa hay is shown in Fig. 3. The fertilized plants were collected from plats fertilized with phosphate at the rate of 100 to 500 pounds per acre. Since these samples were taken from a large number of plats with different rates in the fertilizer application, it would be difficult to show the exact treatment for each plat, hence the plats that received some fertilization with phosphates were used in this study.

Figs. 2 and 3 show that the addition of plant food to the soil does not produce an appreciable change in the effect of soil moisture con-

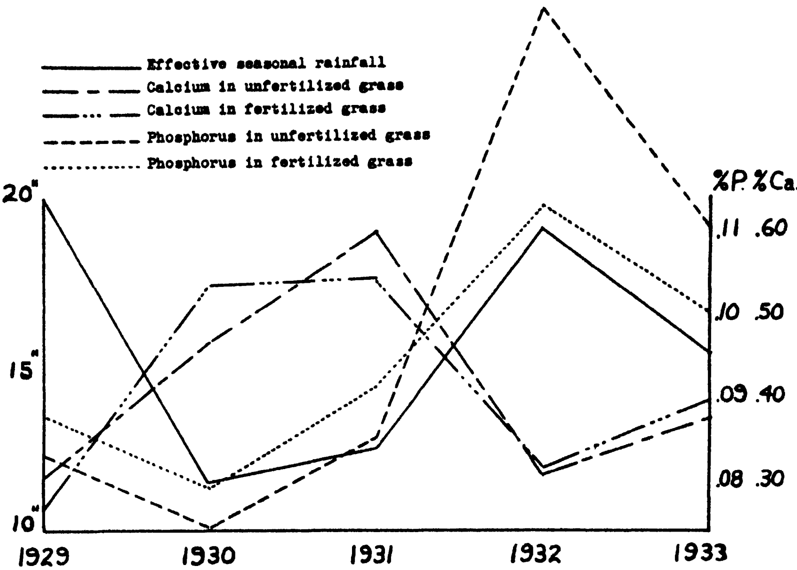

FIG. 2.—The relation between the effective seasonal rainfall and the total calcium and phosphorus content of native prairie hay.

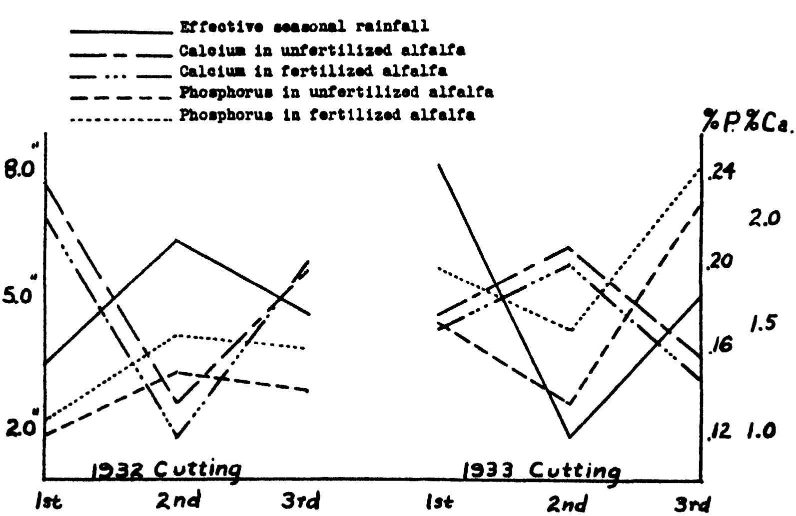

FIG. 3.—The relation between the effective seasonal rainfall and the total calcium and phosphorus content of alfalfa.

ditions on the percentage of calcium and phosphorus in the plant. The addition of phosphorus fertilizers to the soil increased the phosphorus content of all crops of prairie hay except in 1932 and 1933.

The data on calcium was irregular in case of the prairie hay, but was lower in the alfalfa produced on the fertilized plats than in that which grew on the unfertilized area. Apparently calcium applied to the soil as calcium sulfate cannot be used as readily by plants as calcium combined with a weaker anion.

SUMMARY

Thirty samples of little blue stem (*Andropogon scoparius*) were collected each season for 5 years from Kirkland loam soil. Twenty of these samples were taken from plats that were fertilized each year with commercial fertilizer and 10 of the samples were obtained from unfertilized areas. Sixty-eight samples of alfalfa hay were collected from a brown sandy loam, similar to the Bates series of soils, at each cutting for 2 years. Forty-eight samples were taken from plats that were fertilized with commercial fertilizer and farm manure, and 20 samples were obtained from unfertilized soil.

The native grass and alfalfa samples were analyzed for total calcium and phosphorus, and these elements were correlated with the effective seasonal rainfall. During periods when the rainfall was high the calcium content of the plants decreased and the phosphorus content increased. When the effective rainfall was low, the calcium content of the plants increased and the phosphorus content decreased. A knowledge of differences which occur in plant composition is important since mineral deficiencies may or may not be present in forage produced on the same soil during different seasons.

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THE RESIDUAL EFFECT OF ALFALFA CROPPING PERIODS OF VARIOUS LENGTHS UPON THE YIELD AND PROTEIN CONTENT OF SUCCEEDING WHEAT CROPS[1]

W. H. METZGER[2]

THE beneficial effect of legume crops on nonlegumes grown in rotation has long been appreciated. The duration of such beneficial effects and the extent to which the length of the cropping period for a perennial legume influences the residual effect have been less definitely determined. Mirimanian (4)[3] reported a favorable influence from a "prolonged period of cropping to alfalfa" on the yield of succeeding cotton crops in Armenia which was quite pronounced for 3 years. After that the residual effect declined rapidly. Nicol (5) presented data showing the effects of 20 years of previous cropping with eight legumes at the Rothamsted Experiment Station upon succeeding wheat crops. Alfalfa produced the greatest increases in wheat yields and the effect lasted for periods ranging from 5 to 12 years.

An experiment designed to show the nature and extent of duration of the residual effect of alfalfa upon succeeding wheat crops has been in progress at the Kansas Agricultural Experiment Station since 1922. At that time 26 plats, each 1/20 acre in size, were established on land cropped for many years previously to grain crops. Of these 26 plats, 17 were seeded to alfalfa and the remaining 9 seeded to wheat. It was originally planned to plow up one plat of alfalfa sod each year, but after plowing one such plat in 1923 the plan was changed and thereafter duplicate plats were plowed each summer. The last two alfalfa plats were plowed in 1931 and seeded to wheat and since that time the entire area has been cropped uniformly. Beginning with plat No. 2, every third plat has been cropped to wheat continuously. The soil is a silt loam of moderate fertility and the average annual precipitation is 31 inches.

In this experiment the length of time alfalfa occupied the soil varied from 1 to 9 years. Also, the length of time wheat has been continuously cropped on plats on which alfalfa was grown previously has varied from 3 to 11 years. The yields of the plats continuously cropped to wheat were plotted for each year on graph paper and the points thus established were connected. From such a broken line the yields corresponding to continuous cropping to wheat were determined for the plats previously cropped to alfalfa and by comparison with the actual yields for such plats the increases or decreases oc-

[1]Contribution No. 247 from the Agronomy Department, Kansas Agricultural Experiment Station, Manhattan, Kans. Received for publication May 14, 1935.

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[3]Figures in parenthesis refer to "Literature Cited," p. 659.

casioned by alfalfa cropping were calculated. In Fig. 1 the increases and decreases presumably attributable to previous cropping with alfalfa are shown as bushels of wheat per acre.

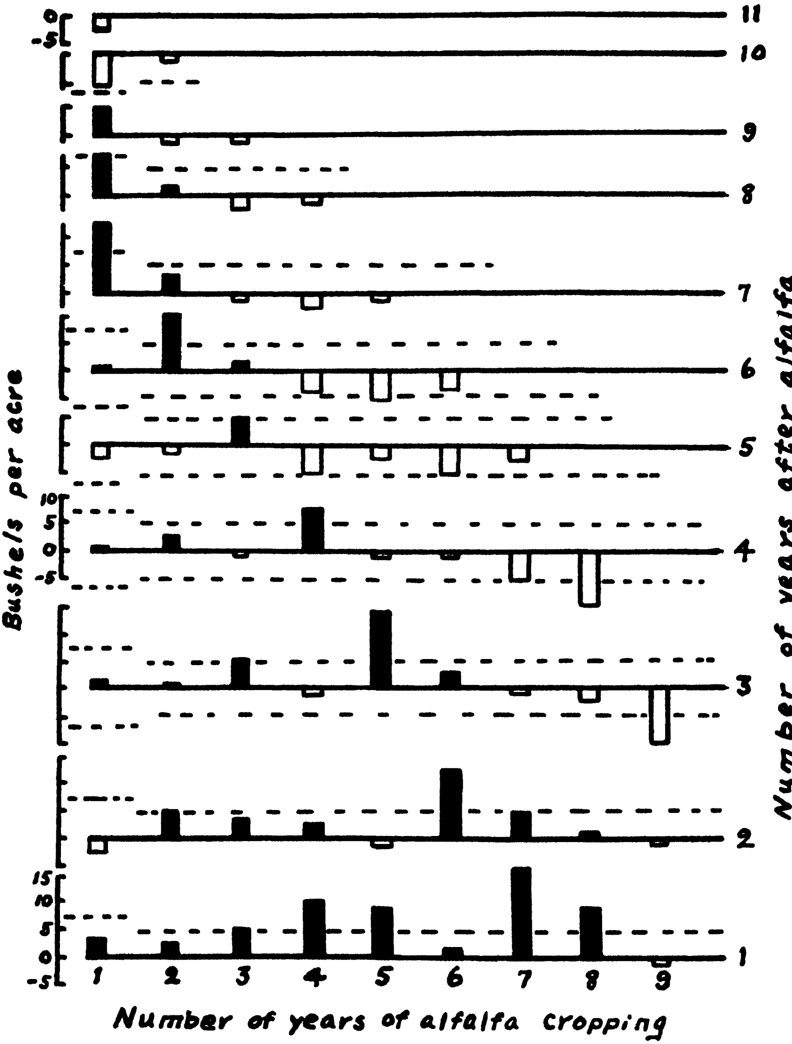

FIG. 1.—Increases and decreases of wheat yields occasioned by previous alfalfa cropping periods of various lengths. Solid blocks indicate increases: open blocks indicate decreases. Broken lines indicate the magnitude of the standard error of the experiment.

Two factors may be prominently active in determining the response of a succeeding crop to the residual effect of alfalfa cropping, i. e., (a) nitrogen supply, and (b) moisture supply. Other factors doubtless are operative in varying degrees. It has been shown by

Duley (1) and by Kiesselbach, Russel, and Anderson (3) that alfalfa very thoroughly depletes the soil moisture supply to considerable depth, and that in regions where rainfall is frequently a limiting factor in crop production, the residual effect on succeeding crops as a result of moisture depletion may become very pronounced. In continuous wheat cropping, where a fallow period of over two months intervenes between harvest and planting time each year, the moisture factor may be of little significance except immediately following the breaking of the alfalfa sod. On the other hand, available nitrogen is ordinarily increased following the plowing under of an alfalfa sod and on soils deficient in available nitrogen this factor tends toward increased yields of succeeding crops.

The yield performance of the wheat crops following alfalfa in this experiment has been somewhat erratic. The interaction of the two factors listed in the preceding paragraph, provided moisture deficiency resulted from previous alfalfa cropping, would tend to produce this result. Another factor which unfortunately has seriously affected the results was the development of foot-rot diseases. This condition was first noticed in 1927, was less prevalent in 1928, became very serious in 1929, was almost wholly absent in 1930, and was only slightly injurious in 1931, while in 1932, 1933, and 1934 the disease was a serious detrimental factor over the entire experiment. It is difficult, therefore, to evaluate the influence of alfalfa on wheat yields in this experiment in 1927, 1929, 1932, 1933, and 1934. Also the diseases, while present in all plats, were distinctly more prevalent during the years 1932, 1933, and 1934 in those plats which had produced alfalfa previous to wheat than in those which produced wheat continuously.[4]

In spite of these diseases, however, the alfalfa appears to have produced conditions tending toward increased wheat yields which extended over a period of several years. The tendency toward uniform increases in yields was confined largely to the first two years of wheat cropping following the various alfalfa cropping periods. However, the year 1930, which was favorable from the standpoint of moisture and temperature conditions and in which diseases were not prevalent, showed increased wheat yields for all plats on which alfalfa grew previously as compared to plats continuously cropped to wheat. This was true regardless of the length of the alfalfa cropping period or the period of wheat cropping following alfalfa. These increases tended to be greater with the longer periods of alfalfa cropping. In those cases where yields were decreased, it is impossible to say to what extent the decreases resulted from residual moisture deficiency or from differential distribution of diseases. Comparative studies of precipitation records and the wheat yields from this experiment point rather definitely toward diseases as the controlling factors.

The standard error of the experiment, determined by the analysis of variance, was ± 6.8 bushels as applied to single plats and

[4]This conclusion is based on field observations of the writer and on charts of the area prepared by Dr. Hurley Fellows, Pathologist of the Division of Cereal Crops and Diseases, U. S. Department of Agriculture.

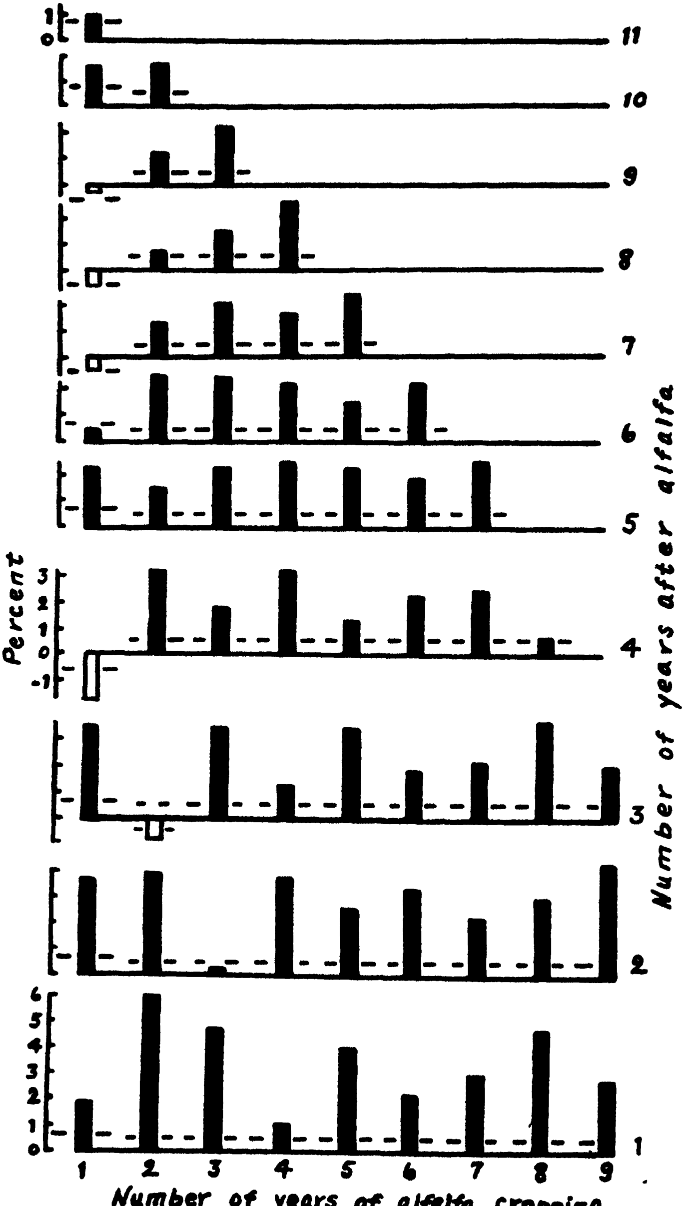

FIG. 2.—Increases and decreases of protein content of wheat occasioned by previous alfalfa cropping periods of various lengths. Solid blocks indicate increases; open blocks indicate decreases. Broken lines indicate the magnitude of the standard error of estimate.

± 4.8 bushels as applied to duplicated plats. These values are indicated in Fig. 1 by the horizontal, broken lines. According to this measure, many of the increases and decreases of yield are of doubtful significance.

The increases and decreases in protein content of the wheat crops resulting from previous cropping to alfalfa are shown in Table 1 and in Fig. 2.

These increases and decreases in protein content were determined on the basis of the regression of protein content upon yield from the plats continuously cropped with wheat. The correlation of protein content with yield from plats so cropped, based on 91 pairs of values from single plats covering a period of 11 years, was $r = -.809 \pm .024$. The data were plotted in Fig. 3, which shows the scatter of the dots about the regression curve. The regression is clearly not linear. The curve was fitted to the data according to the method for fitting a free hand curve described by Ezekial (2). The equation, $\log y = 5.8913 - 4.2369 \log x$, closely approximates the curve.

From the regression curve the protein content corresponding to each yield for plats on which alfalfa was previously grown was estimated. By subtracting each of these values from the corresponding actual protein content, the increases presented in Table 1 were obtained. The use of the regression curve for determination of the values to be compared with the actual protein content data probably largely eliminated the influence of the foot-rot diseases. This statement is based on an assumption that such diseases would prob-

TABLE 1.—*Increases and decreases of protein content of wheat attributable to previous cropping of the land to alfalfa.**

No. years cropped with alfalfa	Increase or decrease in percentage of protein for the year indicated, following the breaking of alfalfa sod					
	1st	2nd	3rd	4th	5th	6th
1	2.00†	3.65†	3.50†	—1.70†	2.20†	0.50†
2	5.98	3.85	—0.80‡	3.17	1.50	2.45
3	4.88	0.23	3.52	1.75	2.25	2.42
4	1.15	3.65	1.30	3.17	2.40	2.27
5	4.00	2.60	3.47	1.30	2.27	1.57
6	2.23	3.20	1.82	2.15	1.90	2.25
7	3.10	2.22	2.17	2.35	2.60	—
8	4.77	2.97	3.67	0.63	—	—
9	2.93	4.27	2.22	—	—	—
	7th	8th	9th	10th	11th	
1	—0.60†	—0.50†	—0.25†	1.60†	1.05†	
2	1.27	0.73	1.23	1.67	—	
3	1.95	1.47	2.32	—	—	
4	1.75	2.67	—	—	—	
5	2.35	—	—	—	—	
6	—	—	—	—	—	
7	—	—	—	—	—	
8	—	—	—	—	—	
9	—	—	—	—	—	

*Average of duplicate plats except where otherwise noted.
†Based on results from one plat only.
‡Decreases are preceded by a negative sign (-).

ably tend to increase the protein content in about the same proportion to the reduction in yield as was established in the regression curve. The writer knows of no experimental work in which factors have been so segregated as to permit of verification of this assumption.

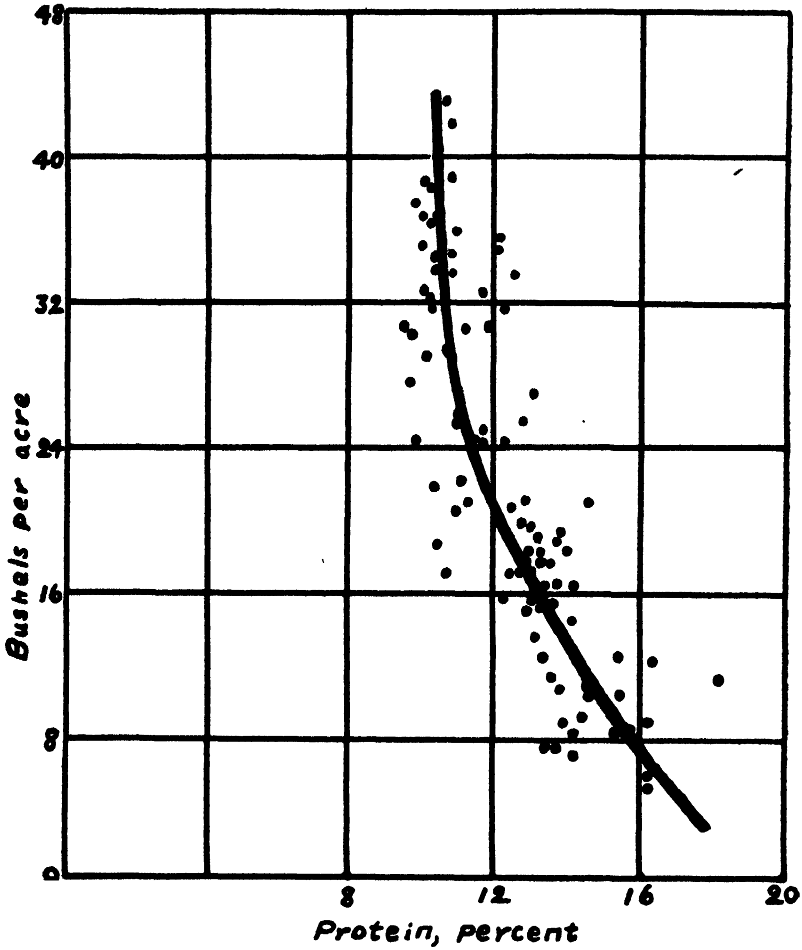

FIG. 3.—Protein content-yield regression curve for wheat produced in continuous culture.

The fact that increases so calculated for years in which foot-rots were largely or wholly absent compare favorably with those for years when the diseases were very prevalent lends weight to the validity of crediting the increases for the latter group of years wholly to the influence of the alfalfa crop.

The protein content data indicate quite consistent and, for the most part, highly significant increases attributable to the alfalfa. The broken horizontal lines in Fig. 2 indicate the magnitude of the standard error of estimate as applied to the estimated protein con-

tents derived from the regression curve. The standard error of estimate as determined for data from single plats was ± .69%. As applied to averages of duplicated plats this value was ± .488, hence the shift in the broken lines in the graph to the right of the first vertical column. Most of the increases exceed twice these values.

The protein data indicate that the residual effect of alfalfa, especially if the crop is allowed to remain on the soil 2 or more years, may be reflected in succeeding crops for a period of at least 10 years under the climatic and soil conditions represented by this experiment. Whether this effect reaches a maximum before or at the completion of 9 years of cropping with alfalfa is not revealed by the data. The effect of from 1 to 3 years of alfalfa, however, seems definitely to be decreased after 9 years or more of continuous wheat.

Seasonal effects are apparent in the data. The year 1927 was characterized by very high rainfall in June, and only small protein increases, along with some decreases, are creditable to alfalfa for that year. In 1933 and 1934 the June rainfall was very low and protein values for wheat on the alfalfa plats were decidedly in excess of those for the continuous wheat plats.

SUMMARY

An attempt has been made at the Kansas Agricultural Experiment Station to measure the residual effect of alfalfa cropping upon yield and protein content of succeeding wheat crops.

Foot-rot diseases seriously limited the value of the yield determinations in certain years after the third wheat crop of the experiment. When these diseases were absent, alfalfa produced favorable effects on yields of succeeding wheat crops. When the diseases were prevalent continuously cropped wheat plats produced the larger yields. An attempt was made to eliminate this factor in the evaluation of the protein data. All periods of alfalfa cropping, varying from 1 to 9 years, produced increases in protein content of wheat.

Alfalfa cropping for as short a period as 2 years produced a favorable residual effect measurable by succeeding wheat crops over a period of at least 8 years. The longer periods of alfalfa cropping produced greater residual effects. Whether the maximum was reached in less than 9 years of alfalfa cropping the data do not clearly reveal.

It appears that residual effects may continue to be manifested longer in protein content than in yield. Diseases in the wheat in this experiment, however, have not permitted a clear verification of this statement.

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EFFECT OF SOIL TEMPERATURE AND DEPTH OF PLANTING ON THE EMERGENCE AND DEVELOPMENT OF SORGHUM SEEDLINGS IN THE GREENHOUSE[1]

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SORGHUMS are of tropical origin and have long been known to germinate and grow best at relatively high temperatures. Both seeds and seedlings of sorghum are very sensitive to environmental conditions. Experiments are under way to determine the causes of seed rotting and seedling blights of sorghums and the soil temperature and other factors influencing them. Data were recorded on the germination and development of sorghum seedlings grown at five soil temperatures and three depths of planting in one of the pathological experiments, and these data are presented here.

MATERIAL AND METHODS

The varieties studied were Standard feterita, Dwarf Yellow milo, Dawn kafir, and White Italian broomcorn, each being representative of rather distinct groups. Feterita has large, soft, starchy seeds that germinate quickly but are subject to rotting in cold wet soil. The seedlings also are rather large and the plants mature early. The milo seeds and seedlings are somewhat smaller than those of feterita and the seeds usually germinate slightly slower and are less subject to rotting. Milo matures later than feterita. Kafir seeds are smaller and harder than those of milo, germinate more slowly, and are less subject to rotting in the field. The seedlings are much smaller than those of milo and the plants mature later. Broomcorn seeds are hard and germinate slowly. They are usually enclosed in the glumes and are fairly resistant to rotting under field conditions. The seedlings are somewhat larger than those of Dawn kafir and the plants mature in about the same period.

The seeds were planted on March 26, 1930, in the greenhouse at the Arlington Experiment Farm, Rosslyn, Va., near Washington, D. C. Local soil containing 1 part in 4 of leaf mold was used and the moisture content was maintained at about 60% of the maximum water-holding capacity. The seeds in half of the cans were untreated, but the remainder were dusted with copper carbonate. The soil temperature control equipment used, except for minor modifications, has already been described.[3] The soil temperatures were maintained at approximately 15°, 20°, 25°, 30°, and 35° C, and seeds were planted at ½-, 1½-, and 2½-inch depths.

The data here presented are based upon determinations in a total of 144 soil cans planted at the rate of 25 seeds per can. There were five temperatures, three planting depths, and two seed treatments of each of four varieties, requiring a total of 120 soil cans. The re-

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[3]LEUKEL, R. W. Equipment and methods for studying the relation of soil temperature to diseases in plants. Phytopath., 14 : 384–397. 1924.

maining 24 cans were a duplication of the 15° C soil temperatures, sterilized soil having been used. Germination and stage of growth were recorded daily. The other measurements were taken approximately when the plants had reached the 5-leaf stage. The plant measurements are averages of 10 plants in each can except in a few cases where the total number of available plants was less.

RESULTS OBTAINED

Data secured were percentage of germination, date of emergence, increase in number of leaves, lengths of the coleoptile and subcrown internode, and numbers of crown roots and subcrown rootlets. The figures presented represent averages for all treatments of each variety or for all varieties at each treatment. Data from the $CuCO_3$-treated seeds were averaged with those from the untreated seeds. The data from the plants in the steam-sterilized soil were averaged with those grown in unsterilized soil at the same temperature (15° C), except in the case of germination percentages which were affected favorably by soil sterilization.

VARIETAL DIFFERENCES

The average measurements recorded on emergence and development of each of the four varieties are shown in Table 1. The germination of the Dawn kafir seeds was weaker and slower than that of other varieties. The differences in growth rate after emergence were not important. The average coleoptile length was proportional to the size of the seedlings of the four varieties, Standard feterita having the longest and Dawn kafir the shortest. The broomcorn and feterita plants had the longest subcrown internodes, and the broomcorn plants had the most numerous roots.

TABLE 1.—*Measurements of germination and plant parts of four sorghum varieties.**

Variety	Germination %	Time of emergence, days†	Emergence to 4-leaf stage, days*	Coleoptile length, mm	Subcrown internode length, mm	Crown roots, number	Subcrown rootlets, number
Standard feterita	72	6.3	14.4	11.3	42.7	2.5	2.4
Dwarf Yellow milo	78	6.4	17.8	9.3	36.9	2.6	3.4
Dawn kafir	65	9.1	15.1	6.6	36.2	2.0	3.8
White Italian broomcorn	86	7.2	16.0	8.9	44.0	3.1	4.4

*Average of all treatments.
†Majority of plants.

EMERGENCE

The rate of and time for emergence and the period from emergence to the 4-leaf stage at different soil temperatures and depths of planting are shown in Table 2. There was a decrease in the average germination percentage at the temperatures below 25° C. The seeds planted at a depth of 2½ inches showed almost as high an average germi-

nation as at the shallower depths of planting, but there was a distinctly low germination from deep planting at the cool 15° C temperature. The seedlings emerged from the 1½ and 2½ inch depths of planting about as quickly as from the ½-inch planting except at the 15° temperature, where there was a noticeable difference. Emergence was delayed distinctly at soil temperatures below 25° C. The period between emergence and the 4-leaf stage increased progressively from 9 to nearly 24 days as an average, as the soil temperatures dropped from 35° to 15° C. This shows an effect on plant growth by soil temperature where the air temperature was uniform for all soil treatments. Differences in rapidity of development at the three planting depths were small and unimportant.

TABLE 2.—*Rate and time of emergence of sorghum seedlings from planting at three depths in each of five soil temperatures.**

Depth of planting, inches	Soil temperature, °C					
	15°	20°	25°	30°	35°	Average
	Rate of Emergence %					
0.5	71.0	80.5	79.0	77.0	82.0	79.9
1.5	58.0	75.0	80.0	83.5	82.5	79.0
2.5	56.5	72.5	78.5	82.0	74.0	75.1
Average	61.8	76.0	79.2	80.8	79.5	—
	Time of Emergence, Days					
0.5	6	7	5	4	4	5.2
1.5	9	8	4	4	4	5.8
2.5	11	8	5	4	5	6.6
Average	8.7	7.7	4.7	4.0	4.3	—
	Time from Emergence to 4-leaf Stage, Days					
0.5	22	15	12	11	9	13.8
1.5	24	14	13	10	9	14.0
2.5	25	16	12	11	9	14.6
Average	23.7	15.0	12.3	10.7	9.0	—

*Average of four varieties.

SEEDLING DEVELOPMENT

The effect of soil temperature and depth of planting upon the length of the coleoptile and subcrown internode and upon the number of crown roots and subcrown rootlets is shown in Table 3. The length of the coleoptile decreased slightly with an increase in soil temperature and with decreased planting depth. The coleoptile does not grow all the way upward from the seed because most of the elongation takes place in the subcrown internode (Fig. 1) below the coleoptile. The base of the coleoptile is thus pushed up nearly to or even above the soil surface. The length of the subcrown internode thus depends largely upon the depth of planting, as the data indicate. The internode length is seen to be directly proportional to the depth of planting. The subcrown internodes were considerably longer at soil temperatures above 20° than at 20° or 15° C. This

greater elongation forced the base of the coleoptile above the soil surface at high temperatures and necessitated the formation of the crown and the first growth of crown roots in the air (Fig. 1, 3).

FIG. 1.—Feterita seedlings planted at a depth of 1 inch in soil at 15° (1), 20° (2), and 25° C (3). The horizontal line shows the location of the soil surface. (a) Coleoptile, (b) crown, (c) crown roots, (d) subcrown internode, (e) subcrown rootlet, (f) seed, (g) seminal root. Note the difference in the length of subcrown internode and height of crown due to soil temperature differences. Sorghums produce only a single seminal root.

TABLE 3.—*Length of coleoptile and subcrown internode and number of roots on sorghum seedlings from planting at three depths at each of five soil temperatures.**

Depth of planting, inches	Soil temperature, °C					
	15°	20°	25°	30°	35°	Average
	Coleoptile Length, mm					
0.5	8.6	8.5	9.4	8.2	6.9	8.4
1.5	9.7	9.7	9.4	7.9	6.9	8.8
2.5	11.0	10.2	9.5	8.4	7.3	9.3
Average	9.9	9.5	9.4	8.2	7.0	—
	Subcrown Internode Length, mm					
0.5	16.1	17.5	25.0	26.1	22.0	21.6
1.5	31.4	38.5	40.9	42.9	40.7	38.8
2.5	52.3	63.2	67.3	68.5	68.9	64.2
Average	33.3	39.8	44.4	45.9	43.9	—
	Crown Roots, Number per Plant					
0.5	2.7	3.2	2.2	2.8	3.4	2.8
1.5	2.1	2.9	2.5	2.6	3.4	2.7
2.5	1.3	2.7	2.7	2.4	2.9	2.4
Average	2.0	2.9	2.5	2.6	3.2	—
	Subcrown Rootlets, Number per Plant					
0.5	0.7	[illegible]	1.0	1.3	1.0	1.0
1.5	1.7	3.0	3.2	5.0	4.7	3.5
2.5	4.6	5.8	6.9	7.8	7.6	6.5
Average	2.3	3.1	3.7	4.7	4.6	—

*Average of 4 varieties.

The depths of planting of approximately 13, 38, and 63 mm are less than the average internode length and suggest that a majority of the plants at soil temperatures of 25° C or higher formed crowns above the surface of the soil. Crown roots grew downward until they entered the soil. Many of the subcrown internodes were so flexible that the weight of the seedling forced the crown down to the surface of the soil. Under field conditions such high crowning, even at high temperatures, is not observed frequently because the washing and drifting of the soil tend to fill up the planter furrows and thus cover the crowns. Lack of light also causes the subcrown internode to be abnormally long.[4]

There was some indication of fewer crown roots and a distinct tendency for fewer subcrown rootlets as the soil temperatures decreased. Deep planting tended to reduce the number of crown roots but greatly increased the number of subcrown rootlets. Sorghum

[4]HAMADA, H. Wachstumverhältnisse der Keimorgane von verschiedenen Gramineen im Dunkel und Belichtung mit besonderer Berücksichtigung ihrer systematischen Stellung. Mem. Col. Sci., Kyoto Imp. Univ., Ser. B, 19 : 71–128. 1933.

plants produce only a single seminal root (Fig. 1).[5] Until crown roots are formed, the plants must secure their soil nutrients from the single root and the subcrown rootlets. The subcrown internode is longest from deep planting at high soil temperatures. The greater length of the subcrown internode where rootlets can develop may account largely for the greater number of subcrown rootlets from deep planting and high soil temperatures.

SUMMARY

The percentage and rapidity of germination in sorghums were reduced by soil temperatures below 25° C and slightly reduced by deep planting (2½ inch). Seedling development was retarded by lower soil temperatures within the range from 35° to 15° C. Development also was retarded by deep planting at 15° C soil temperatures but not at higher temperatures.

The length of the coleoptile of sorghum seedlings was greatest in varieties producing large seedlings and was increased slightly by deep planting and low soil temperatures.

The length of the subcrown internode varied directly with the depth of planting and was increased by soil temperatures above 25° C. At high soil temperatures, many of the seedlings formed their crowns above the soil surface.

The number of crown roots was generally greatest from shallow planting at high soil temperatures.

The number of subcrown rootlets was greatest from deep planting at high soil temperatures.

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[5]SIEGLINGER, J. B. Temporary roots of the sorghums. Jour. Amer. Soc. Agron., 12 : 143–145. 1920.

THE DECREASE IN YIELDING CAPACITY IN ADVANCED GENERATIONS OF HYBRID CORN[1]

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THE exclusive use of first generation seed for the production of hybrid corn runs counter to the traditional practice of the farmer who is accustomed to saving his own supply. The generally superior performance of tested and adapted hybrids greatly enhances the temptation to take seed from the crop; and, in some cases at least, the rather attractive appearance of the advanced generations themselves tends to mask the decline in productivity which has occurred. As a basis for efficient practice, it is important, therefore, that a well-founded body of fact be established concerning the value of first generation hybrid seed as compared with that taken from later generations.

Wright (4)[3] has pointed out that "a random-bred stock derived from n inbred families will have $\frac{1}{n}$ th less superiority over its inbred ancestry than the first cross or a random-bred stock from which the inbred families might have been derived without selection." The main object of the present study was to determine whether, on the average, this generalization holds for corn and to ascertain if, in particular cases, the departures from it were large enough to be significant in practice.

Tests were made in 1933 and 1934 to determine the relative yielding capacities of the first and succeeding generations of hybrid strains. In the first season's trials, precautions were not taken to avoid competition effects between the F_1 and F_2 generations. The present report involves only the data obtained in 1934.

MATERIALS AND METHODS

The material used in the test consisted of 10 single, 4 three-way, and 10 double hybrids and their F_2 generations, as well as the F_3 generations of 8 of the single and 3 of the three-way hybrids. Reference to Table 1 shows the various hybrids comprising the same group of inbred lines. Lines 25 and 26 are closely related.

The F_2 seed of certain of the single hybrids was taken from the bulked seed obtained from a series of crossing plats in which the single hybrids were the respective male parents. In these instances the seed used was obviously the result of random pollination. The F_2 seed of some of the three-way and double hybrids, having been harvested from uncontaminated field crops of the respective hybrids, was likewise the product of random pollination. In all other cases the seed

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[3]Figures in parenthesis refer to "Literature Cited," p. 670.

	Yield, bus. per acre				Decrease, bus. per acre			Decrease %		
	Actual			Expected	Actual		Expected	Actual		Expected
	F_1	F_2	F_3	F_2 and F_3	F_1–F_2	F_1–F_3	F_1–F_2 or F_3	F_1–F_2	F_1–F_3	F_1–F_2 or F_3
Single Hybrids										
$(3 \times R_3)$	59.2	45.7	52.6	40.4	13.5	6.6	18.8	22.8	11.3	31.75
$(R_3 \times 6)$	60.7	47.0	45.2	43.0	13.7	15.5	17.7	22.6	25.5	29.16
$(R_3 \times 25)$	61.2	43.7	48.8	41.5	17.5	12.4	19.7	28.6	20.3	32.19
$(R_3 \times 26)$	55.4	34.8	—	38.5	20.6	—	16.9	37.2	—	30.50
(3×25)	70.9	41.7	45.7	47.4	29.2	25.2	23.2	41.2	35.5	32.72
(3×26)	68.1	44.7	—	46.3	23.4	—	21.8	34.4	—	32.01
(6×26)	67.6	52.6	50.5	47.9	15.0	17.1	19.7	22.2	25.3	29.14
$(M_{13} \times R_3)$	58.4	40.9	42.7	39.7	17.5	15.7	18.7	30.0	26.9	32.02
$(R_3 \times 23)$	59.9	44.5	46.0	41.6	15.4	13.9	18.3	25.7	23.2	30.55
(23×26)	66.8	46.5	49.0	46.5	20.3	17.8	20.3	30.3	26.7	30.38
Average	62.8	44.2	47.5	43.3	18.6	15.5	19.5	29.5	24.3	31.05
Three-way Hybrids										
$(R_3 \times 3) \times 25$	66.3	49.0	48.5	51.9	17.3	17.8	14.4	26.1	26.9	21.72
$(3 \times 25) \times R_3$	60.9	44.7	48.3	47.8	16.2	12.6	13.1	26.6	20.7	21.51
$(R_3 \times 25) \times 6$	69.1	56.9	—	55.0	12.2	—	14.1	17.7	—	20.40
$(6 \times 25) \times R_3$	60.7	46.5	45.5	48.3	14.2	12.4	12.4	23.4	25.0	20.43
Average	64.2	49.3	47.4	50.7	14.9	14.3	13.5	23.4	24.2	21.01
Double Hybrids										
$(R_3 \times 6)(23 \times 25)$	64.3	52.0	—	54.7	12.3	—	9.6	19.1	—	14.93
$(M_{13} \times R_3)(6 \times 25)$	57.9	50.0	—	49.5	7.9	—	8.4	13.6	—	14.5
$(3 \times R_3)(23 \times 25)$	68.1	58.7	—	57.0	9.4	—	11.1	13.8	—	16.29
$(6 \times 25)(3 \times R_3)$	67.6	58.2	—	56.9	9.4	—	10.7	13.9	—	15.83
$(23 \times R_3)(3 \times 25)$	60.5	53.6	—	51.4	6.9	—	9.1	11.4	—	15.04
$(R_3 \times 6)(3 \times 25)$	65.8	55.1	—	55.6	10.7	—	10.2	16.3	—	15.50
$(23 \times R_3)(M_{13} \times 6)$	64.0	52.6	—	54.4	11.4	—	9.6	17.8	—	15.00
$(3 \times 6)(23 \times 25)$	64.5	57.4	—	55.2	7.1	—	9.3	11.0	—	14.42
$(R_3 \times 25)(M_{13} \times 23)$	62.7	45.2	—	52.9	17.5	—	9.8	27.9	—	15.63
$(3 \times R_3)(6 \times 23)$	65.5	56.9	—	55.6	8.6	—	9.9	13.1	—	15.11
Average	64.1	54.0	—	54.3	10.1	—	9.8	15.8	—	15.22

was obtained from hand pollinations. In each such instance at least 40 sound ears were represented, while the pollen was taken from not less than 20 plants.

In the yield trials each strain was replicated six times in a random fashion, each replicate consisting of two 10-hill rows. Four kernels were planted in each hill with no subsequent thinning. Since competition would be expected to exert an influence in favor of the F_1 generation, the latter was separately randomized, though in the same trial area. Thus, in each of the six series, two sub-series were planted, one to the F_1 generation and the other to the F_2 and F_3 generations. It was not expected that there would be any significant competitive effects between the F_2 and F_3 generations and these were accordingly randomized together.

The ears from each plat were harvested separately, dried to 13% moisture, and weighed. The data were analyzed according to the analysis of variance method by Fisher (1) and the acre yields calculated on a shelled corn basis.

The yields of each of the inbred lines which entered into the composition of the various hybrids were likewise determined in 1933 and 1934 and are shown in Table 2. The lower yields obtained in 1934 may be attributed to the severe drought experienced then. The data on the inbred lines probably represent a fairly reliable estimate of their yielding capacities.

The expected yields of the advanced generations were calculated from those of the parent inbred lines and the respective F_1 generations of the hybrids, using Wright's (4) formula. On this basis, the loss of vigor in the F_2 generation when the F_1 is bred *inter se* will vary in inverse proportion to the number of inbred lines involved and may be stated as $\frac{1}{n}$ of the excess vigor of the hybrid over that of the inbreds, where n equals the number of parent lines in the ancestry of the hybrids. In other words one-half, one-third, and one-quarter of the excess vigor of the F_1 generation over the inbred parents will be lost in the F_2 generation when two, three, or four inbred lines, respectively, comprise the parents of the hybrid. Since zygotic equilibrium is reached in the F_2 generation, there should be no further decrease in vigor in the F_3 and succeeding generations, provided mating is completely random and there is no differential selection.

TABLE 2.—*Comparison of the yields of inbred lines in 1933 and 1934.*

Inbred line	Yield, bus. per acre		
	1933	1934	Average
R3	24.4±0.66	18.8±0.84	21.6
3	29.3±0.79	24.4±1.09	26.8
6	33.9±0.91	31.8±1.42	32.8
23	34.9±0.93	27.9±1.25	31.4
25	24.3±0.65	24.6±1.10	24.4
26	21.8±0.58	24.4±1.09	23.1
M13	23.6±0.62	23.1±1.03	23.3

P.E. of inbred lines = ±2.35 and ±1.08 in 1933 and 1934, respectively.

The P_1 yield values were determined by averaging the yields of the respective parent lines for each single and double hybrid. Since in a three-way hybrid one inbred line constitutes 50% of the parentage, this parent was weighted accordingly in deriving the P_1 average. Given the yield of the respective F_1 generations, it was then a simple matter, using Wright's formula, to calculate the expected yield of the respective F_2 generations.

EXPERIMENTAL DATA

The yields of the hybrids, together with the expected yields of the advanced generations and the actual and expected decreases in these from the F_1 generation are presented in Table 1.

The greatest decline in yield occurs with the single hybrids and amounts, on the average, to 29.5%. The double hybrids show the smallest decrease, averaging 15.8%, or about one-half that observed for the single hybrids. The decrease in yield of the three-way hybrids is intermediate and averages 23.4%. These averages are in close agreement with the calculated averages which are, respectively, 31.05%, 21.03%, and 15.29% for the single, three-way, and double hybrids. The coefficient of variability of the deviations is 13.2%. In part, this degree of variability can be attributed to environmental influences as well as to random sampling. It is possible also that some of the departures result from complex types of gene interactions.

The average yield values of the parent lines of the hybrids involved in this experiment are presented in Table 3, together with the actual and calculated percentages of the loss of excess vigor of the hybrids over the P_1 lines.

TABLE 3.—*Comparing the actual loss of excess vigor of hybrids over their parent inbred lines with the calculated loss.*

	Average yield, bus. per acre		Av. diff. F_1-P_1, bushels per acre	Yield F_2, bus. per acre	
	F_1	P_1		Actual	Expected
10 single hybrids....	62.8	23.74	39.06	44.2	43.3
4 three-way hybrids.	64.2	23.75	40.45	49.3	50.7
10 double hybrids...	64.1	25.00	39.10	54.0	54.3

	Loss of vigor in yield of grain			
	Actual		Expected	
	Bus. per acre	%	Bus. per acre	%
10 single hybrids....	18.6	47.6	19.5	50
4 three-way hybrids.	14.9	36.8	13.5	33.3
10 double hybrids...	10.1	25.8	9.8	25

The average actual loss of excess vigor as represented by yield is 47.6%, 36.8%, and 25.8%, respectively, for single, three-way, and double hybrids as compared with expected losses of 50%, 33.3%, and 25%, respectively.

Since gametic equilibrium is reached when the hybrids reproduce, the F_3 generation should yield the same as the F_2 generation, assuming no differential selection. In the case of the single hybrids in this experiment, the average decrease in yield of the F_2 generation from the F_1 generation was 29.5% as compared with an average of 24.3% for the F_3 generations. The difference in yield between the F_2 and F_3 generations of the three-way hybrids is not statistically significant.

Though no precise determinations were made, the stalks and leaves of the advanced generations seemed to exhibit less decline in vigor than was observed in yield of grain. While the proportion of barren and spindly stalks was larger than for the F_1 generation, the stalks of the advanced generation progenies were almost as tall and as leafy as those of the former. This could be explained on the assumption that the hybrids were homozygous for more of the factors determining these characters than they were for those affecting yield.

DISCUSSION

The results herein reported are clearly indicative of what might be expected when the advanced generations of hybrid strains are grown, as is the case when seed is saved from a hybrid crop.

Kiesselbach (2) reports the comparative yields of the F_1, F_2, and F_3 generations of 21 single hybrids and their parent lines. The second and third generation hybrids averaged, respectively, 68% and 66% as much grain yield as the first generation hybrids. Richey, *et al.* (3), working with 10 double hybrids, showed that the yields of the F_2 generations were from 5.0% to 24% less than those of the F_1 generation, with an average of 15.2%.

The data presented in this paper are in general agreement with the above. The yield of grain of the parent lines of the hybrids averaged from 37% to 39% of that of the F_1 generations, while the F_2 and F_3 generations of single hybrids averaged, respectively, 70.5% and 75.7%. The yield of the F_2 generations of double hybrids averaged 84.2% of the F_1 generation. In the case of the three-way hybrids, the F_2 and F_3 generations averaged, respectively, 76.6% and 75.8% as much as the F_1 generation. The standard, locally adapted, open-pollinated variety included in this trial yielded 53.1 bushels per acre. The average yield of the F_2 generation of the double hybrids was about the same as that of the variety, while that of the three-way hybrids was almost 4 bushels per acre less.

The results are of further interest in demonstrating that in corn the dissipation of the excess vigor of hybrids over the parent inbred lines is probably in accord with the simple genetical rule which Wright has formulated.

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PRELIMINARY REPORT ON RESISTANCE OF ALFALFA VARIETIES TO PEA APHIDS, *ILLINOIA PISI* (KALT)[1]

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AN opportunity to study the reaction of different alfalfa varieties to pea aphids presented itself in the spring of 1934 in an alfalfa variety test being conducted on the agronomy farm at the Kansas Agricultural Experiment Station. The most severe outbreak of pea aphids on record for eastern Kansas occurred at that time, bottom fields being almost invariably heavily infested, while on the uplands the infestations were lighter. The unusual feature of the infestation was that the fields were rather uniformly infested. The large number of aphids resulted in a stunting and yellowing of infested fields that brought into sharp relief differences between individual plants. In a 4-year-old alfalfa variety test consisting of 36 varieties, the number of plants showing no injury varied greatly enough to make a noticeable difference in the appearance of the plats. Examination of these plants showed that they were infested by fewer aphids than other plants indicating they may be different from others in the variety.

As far as could be ascertained from the literature, the resistance of different commercial varieties of alfalfa has never been noted, although resistance of individual plants of Grimm and other varieties of alfalfa to pea aphid has been reported.[3] Because of the irregularity with which field infestations of pea aphids occur, limiting the opportunity for a study of the reaction of different alfalfa varieties to the insect, it seems advisable to report the information obtained.

In the alfalfa variety test, consisting of 86 1/20 acre plats, all varieties were duplicated, with the exception of Grimm, which was represented by six plats and Kansas common by 12 plats, as checks. These plats were seeded in the fall of 1930 and as all are not wilt and cold resistant the stands were not all uniform at the time the study was made. To secure a measure of the infestation of the different varieties, 20 sweeps with a standard 1-foot square net were made on each plat. After removal of leaves, trash, and the few other insects present, the aphids were measured in a graduated cylinder and the results recorded in cc. A single 20-cc sample which was counted contained 12,630 aphids. An estimate was also made of the percentage of damage on the different plats on the basis of the visible injury resulting from aphid attack. This injury consisted of the stunting

[1]Contribution No. 430, Department of Entomology, and Contribution No. 240, Department of Agronomy, Kansas State College, Manhattan, Kans. Joint contribution of the Departments of Entomology and Agronomy, Kansas Agricultural Experiment Station cooperating with the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Received for publication May 20, 1935.

[2]Associate Professor of Entomology, Kansas State College, and Assistant Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, respectively.

[3]BLANCHARD, R. A., and DUDLEY, JOHN E., JR. Alfalfa plants resistant to the pea aphid. Jour. Econ. Ent., 27 : 262–264. 1934.

and yellowing of the plants and the estimate took into consideration both the severity of the damage and the number of injured or uninjured plants. The figures are comparative and concern only the varieties in the test. These data are recorded in Table 1. (See also Fig. 1.)

TABLE 1.—*Pea aphids on alfalfa varieties.*

Rank	Variety	Record No.	Av. No. of cc*	Av. % injury†	Av. % stand
1	Ladak	15988	22	10	85
2	Turkestan	86696	40	10	95
3	Turkestan	19301	48	22	95
4	Turkestan	19302	48	17	95
5	Turkestan	19299	48	15	95
6	Turkestan	19303	50	20	95
7	Turkestan	19300	54	22	95
8	Hardistan	——	56	20	95
9	Turkestan	15754	59	20	95
10	Turkestan	19304	61	37	95
11	Hardigan	18777	61	55	40
12	Acc'l Grimm	19305	61	72	10
13	French	19274	63	52	72
14	Hungarian	81438	65	55	47
15	Turkestan	85751	66	15	95
16	*Grimm* (6 plats)	307	66	62	34
17	Blue Ukranian	19315	67	70	12
18	German	91502	67	62	32
19	Hungarian	15706	72	72	22
20	French	19273	77	60	62
21	Utah	15986	76	67	32
22	Argentine	15996	77	80	57
23	Dakota No. 12	15997	79	75	45
24	*Kansas common* (12 plats)	306	79	62	58
25	Utah	15995	80	72	25
26	French	81489	87	62	65
27	Baltic	15989	87	57	47
28	Italian	85994	87	47	60
29	Italian	85995	89	42	60
30	Italian	85993	90	42	60
31	French	81448	92	70	60
32	Cossack	18836	92	40	80
33	French	19225	96	70	70
34	Kansas	308	108	55	92
35	Dakota	16081	110	75	40
36	Turkestan	19316	127	70	92

*Twenty sweeps of a 1-foot square net measured in a graduated cylinder.

†Percentage injury is the visible injury, i.e., weak plants nearly killed in the spring, and curling and stunting of plants, April 17, 1934.

There is a range in the average number of cc of aphids for 20 sweeps from 22 cc for Ladak to 127 cc for Turkestan, F. C. 19316. An examination of the plats showed that the visible injury agreed in general with the results of the sweeping. Most of the plats contained individual plants which were apparently more or less resistant to the aphids. In Ladak there were only a few plants heavily infested or badly injured by aphids. These plants contributed most of the aphids swept from the plats of this variety.

Some variation existed between the duplicate plats of the respective varieties. This is partly due to the method of sampling, which is

the only practicable method available. A consideration of the variations which existed in relation to the position of the plats, especially those of Kansas common and Grimm, showed that there were two areas each consisting of several plats where for some reason the number of aphids present was somewhat greater than in the remainder of the plats. This fact, together with the evident differences in stand, explain most of the larger discrepancies. In nearly half of the duplicate plats the difference amounted to 10 cc or less. In Ladak and Turkestan F.P.I. 86696, the duplicates differed by only 2 cc. The important fact is not so much the exact position of the different varieties as it is that some were apparently more resistant than others and that Ladak, a new variety, showed the most resistance. Also the Turkestan varieties grown showed a wide variation in their resistance, but further tests will be necessary to determine their exact positions.

From Table 1 it may be noted that all varieties with stands above 90% had low infestation, with the exception of Kansas 308 and Turkestan F. C. 19316, which had good stands and high infestation. These two strains were also high in pea aphid injury, indicating that the aphids were present and doing damage to the plants. In general, the percentage injury parallels the infestation as measured in cc of aphids. There appears to be one exception to this, Turkestan F. P. I. 85751, which had little injury and a relatively large number of aphids. This agrees with the observation in the field that some plants are able to make normal growth in spite of carrying a heavy infestation of aphids.

In McPherson, Lyon, and Shawnee counties, a heavy infestation occurred in cooperative alfalfa variety tests where Ladak was grown under comparable farm conditions with commonly grown varieties.

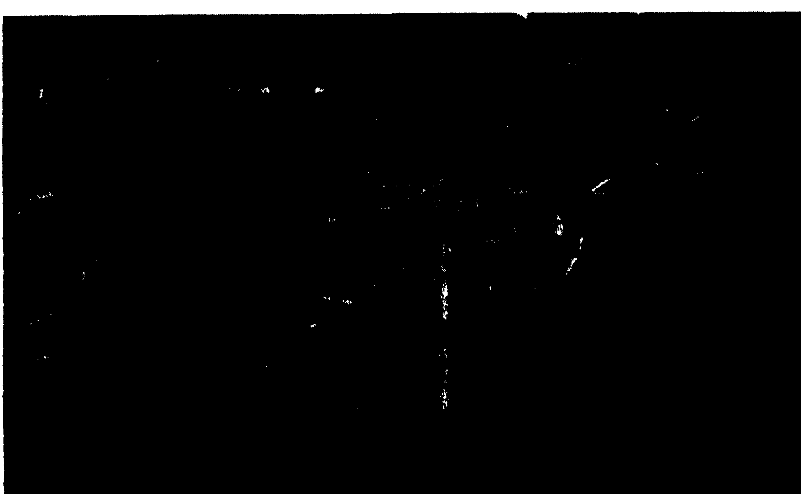

FIG. 1.—Plants resistant (right) and susceptible (left) to pea aphids growing in a field of Kansas common alfalfa.

In these tests, Ladak was infested and damaged in every case to a smaller extent than other varieties. In the tests in McPherson and Lyon counties, the infestation was very heavy, and the difference between Ladak and the other varieties was as great as at Manhattan. Ladak was injured from 0 to 10%, while Kansas common, Grimm, and several other sorts were injured 50 to 75%. In the Shawnee County test, the infestation and damage was not as great, but the results were similar so far as the varieties were the same.

In addition to these records, C. E. Crews, in charge of the south central Kansas experimental fields near Kingman and Wichita reported that Ladak appeared much less susceptible than other varieties under a moderate infestation of the pea aphids.

From a study of the nursery rows, consisting of almost 500 recent importations, it was evident from the estimate of pea aphid damage that the Turkestans as a group were injured less than other varieties. No other group of alfalfas originating from a single region showed as much resistance to pea aphid injury.

In the alfalfa breeding nursery there are selfed lines in the third generation. Here it was possible to compare the resistance of the original plant with that of selections in the third generation of self pollination. In one case it was found that the original plant and most lines from this plant were highly resistant to pea aphid injury. In all other lines it was evident that segregation was still going on. Studies are being conducted to learn more about the inheritance of pea aphid resistance.

GRAZING TIME OF BEEF STEERS ON PERMANENT PASTURES[1]

M. A. HEIN[2]

IN the course of a pasture experiment at Beltsville, Md., data were collected on the time animals spend in grazing. These permanent pastures were located on the Animal Husbandry Farm and were used in a cooperative pasture management experiment with beef cattle.

PROCEDURE

The method used was to keep a record of the time the animals actually spent in grazing during a continuous 24-hour period from 6 a. m. one day to 6 a. m. the following day. Records were taken every 15 minutes during this period. These data were collected for three 24-hour periods in 1931 and in 1932. In 1931 the animals were so marked that it was possible to obtain data on the individual animals without disturbing their normal habits, but in 1932 this was not possible and the records were taken as a group for each pasture.

Four pastures were located adjacent to each other and grazed with three lots of animals. Pasture A-1 (light continuous grazing) contained 8 acres grazed at the rate of one animal to 2 acres, A-2 (heavy continuous grazing) 5 acres with one animal per acre, while A-3 North and A-3 South (heavy alternate grazing) were 2 acres each with one animal per acre. The animals were long yearlings or short 2-year-old steers in thrifty condition and during the periods of collecting the data they were making an average daily gain from 0.75 to 2.00 pounds per head. In 1931, the pastures furnished an abundance of herbage, but in 1932 a shortage of rainfall in the summer limited the grass growth after July, especially on the heavily grazed pastures.

RESULTS

The records obtained in 1931 (Tables 1, 2, and 3) indicate that, in general, animals in the same pasture graze as a group, all spending about the same time in grazing. Steer No. 86 was an exception, but it was observed that he was of a more nervous temperament than the others. From the weight records obtained at 28-day intervals, the individual animals of similar temperament, grazing the shorter time, made slightly higher gains. The time spent in grazing, however, was influenced more by the comparative abundance of the pasturage than by the peculiarities of the individual animal. This is brought out when the average grazing time of lot 3 in 1931 is compared with lots 1 and 2 on the three different days. On September 20 and October 9, lot 3 spent on the average 2 hours more time per day grazing than did lots 1 or 2, while on October 2 all lots averaged about the same time. On October 2, lot 3 had just been moved to the other pasture which had not been grazed for two weeks

[1]Contribution from the Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Studies conducted cooperatively with the Bureau of Animal Industry, U. S. Dept. of Agriculture. Received for publication May 29, 1935.

[2]Associate Agronomist.

and contained an abundance of forage, while on September 20 and October 9, lot 3 was on a pasture that was very closely grazed.

Similar results were obtained in 1932 (Table 4). On July 21, it will be noted that lot 3 averaged slightly over 2 hours more time

TABLE 1.—*Grazing time of individual steers in a 24-hour period, September 20, 1931.*

Lot 1, Light Continuous Grazing

	Steer No.								Average	
	77		84		90		91			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	5	15	5	15	5	0	5	15	5	11
6 p.m. to 6 a.m.	3	15	3	45	3	45	3	45	3	38
Total....	8	30	9	0	8	45	9	0	8	49

Lot 2, Heavy Continuous Grazing

	Steer No.										Average	
	80		81		83		86		87			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	5	15	5	15	5	15	5	30	5	15	5	18
6 p.m. to 6 a.m.	3	45	3	30	2	45	4	15	2	0	3	15
Total....	9	0	8	45	8	0	9	45	7	15	8	33

Lot 3, Heavy Alternate Grazing

	Steer No.								Average	
	73		79		82		85			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	5	0	5	0	5	0	5	0	5	0
6 p.m. to 6 a.m.	5	0	5	15	5	15	6	15	5	26
Total....	10	0	10	15	10	15	11	15	10	26

Temperature: Maximum 96° F; minimum 67° F. Sunrise 5:55 a.m., sunset 6:07 p.m.

in grazing than lots 1 and 2 and on this date the pasture was very closely grazed before removing the animals. The records of July 2 and August 23 were taken just after the animals had been moved to the pasture, which had had an opportunity to recover and again the time of grazing was about equal for all three lots.

The differences are not so pronounced between the continuously light and heavygrazed pastures for the reason that the herbage supply was not reduced as rapidly on the continuously heavy grazed

TABLE 2.—*Grazing time of individual steers in a 24-hour period October 2, 1931.*

Lot 1, Light Continuous Grazing

	Steer No.								Average	
	77		84		90		91			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	6	30	7	0	7	45	6	15	6	53
6 p.m. to 6 a.m.	3	15	3	0	2	15	2	15	2	41
Total....	9	45	10	0	10	0	8	30	9	34

Lot 2, Heavy Continuous Grazing

	Steer No.										Average	
	80		81		83		86		87			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	5	0	5	45	5	45	6	45	5	45	5	48
6 p.m. to 6 a.m.	3	0	2	45	2	30	2	30	3	0	2	45
Total....	8	0	8	30	8	15	9	15	8	45	8	33

Lot 3, Heavy Alternate Grazing

	Steer No.								Average	
	73		79		82		85			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	6	15	6	15	6	15	5	45	6	8
6 p.m. to 6 a.m.	2	15	2	15	2	30	3	0	2	30
Total....	8	30	8	30	8	45	8	45	8	38

Temperature: Maximum 86° F; minimum 52° F. Sunrise 6:06 a.m.; sunset 5:48 p.m.

pasture as on the alternately heavy grazed pasture, where the same number of animals were confined to a smaller area. In 1932, when the herbage was less abundant, the animals on the continuously heavy grazed pasture averaged 31 minutes more time per 24-hour period in grazing than did the animals on the continuously light grazed pastures.

Comparing the 1931 and 1932 results, it will be noted that on the average, the animals spent more time in grazing in 1932 than in 1931, which can be accounted for in the less abundant herbage in the pastures in 1932 due to lack of rainfall.

TABLE 3.—*Grazing time of individual steers in a 24-hour period, October 9, 1931.*

Lot 1, Light Continuous Grazing

	Steer No.								Average	
	77		84		90		91			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	5	15	5	0	7	30	4	45	5	38
6 p.m. to 6 a.m.	1	30	3	0	1	45	2	45	2	15
Total....	6	45	8	0	9	15	7	30	7	53

Lot 2, Heavy Continuous Grazing

	Steer No.										Average	
	80		81		83		86		87			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	6	45	7	30	6	30	8	45	6	30	7	12
6 p.m. to 6 a.m.	2	45	2	30	1	45	1	15	1	15	1	54
Total....	9	30	10	0	8	15	10	0	7	45	9	6

Lot 3, Heavy Alternate Grazing

	Steer No.								Average	
	73		79		82		85			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	8	30	9	0	9	0	9	30	9	0
6 p.m. to 6 a. m.	1	30	2	15	1	30	2	15	1	53
Total	10	0	11	15	10	30	11	45	10	53

Temperature: Maximum 70° F; minimum 38° F. Sunrise 6:13 a.m.; sunset 5:37 p.m.

In the course of the two years some rather interesting observations were made on the grazing activities which are not apparent from the data recorded. The animals did not graze at night expect when it was moonlight or when the visibility was good, as in the twilight. If a fog came up they "bedded down" in a very short time. They grazed more intensively between 5 p. m. and 8 p. m. and between 5 a. m. and 8 a. m. than at any other period during the 24 hours.

On hot days grazing began somewhat earlier in the morning and, after the mid-day rest, was resumed later in the evening, while if the day was cool a little more time was spent in grazing during mid-day. In general, however, it seemed that there were two rather definite grazing periods in each 24 hours.

In a more detailed study of the various activities of grazing animals in North Dakota[3] and Texas,[4] similar observations on the grazing habits of livestock were made. In North Dakota beef steers on sweet clover pasture spent 8¼ hours in grazing, while in Texas cattle on range pasture spent about 7¾ hours during a 24-hour period. The results obtained in Texas are an average of 36 observations made during the period from January 1924 to December 1926.

TABLE 4.—*Grazing time in 24-hour period on three different dates in 1932.*

	July 2*		July 21†		August 23‡		Average	
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
Continuous Light Grazing								
6 a.m. to 6 p.m.	4	50	5	10	7	15	5	45
6 p.m. to 6 a.m.	5	5	3	45	3	20	4	3
Total	9	55	8	55	10	35	9	48
Continuous Heavy Grazing								
6 a.m. to 6 p.m.	5	8	5	0	8	4	6	4
6 p.m. to 6 a.m.	5	12	4	44	2	48	4	15
Total	10	20	9	44	10	52	10	19
Heavy Alternate Grazing								
6 a.m. to 6 p.m.	4	30	7	25	7	15	6	23
6 p.m. to 6 a.m.	4	50	4	0	2	55	3	55
Total	9	20	11	25	10	10	10	18

*Night clear, no moon, N. W. wind. Poor visibility between 8:45 p.m. and 3:30 a.m. Cold for this season of the year. Maximum 81°, minimum 58°.

†Cloudy, visibility better than on July 2. High humidity, three showers during the day; hot and muggy. Maximum 90°, minimum 67°.

‡Cool, cloudy night; moon rose at 11:30 p.m. Heavy fog from 2 a.m. to 5:30 a.m. Hot day, no clouds. Maximum 88°, minimum 51°.

SUMMARY AND CONCLUSIONS

The factor that affected the total time spent in grazing during a 24-hour period was the amount of feed present.

When the pastures furnished an abundance of forage, approximately 8¾ hours of a 24-hour period were spent in grazing. When herbage was not so plentiful, approximately 10 hours were spent in grazing.

Approximately 66% of the grazing occurred during the daylight period from 6 a. m. to 6 p. m.

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[3]SHEPPERD, J. H. Sweet clover experiments in pasturing. N. D. Agr. Exp. Sta. Bul. 211. 1927.

[4]CORY, V. L. Activities of livestock on the range. Tex. Agr. Exp. Sta. Bul. 367. 1927.

NOTES

THE ADAPTATION OF CORN TO CLIMATE

THE article on "The Adaptation of Corn to Climate" which appeared recently in this JOURNAL (Vol. 27, pages 261 to 270), is interesting and stimulating. Agronomists may well maintain open minds regarding the factors involved in the ecological relations of crop plants. However, the value of correlating individual facts to develop working hypotheses must depend largely on whether the data used are typical for the problem awaiting solution. The validity of an ecological theory may be tested by its success or failure in explaining responses to the same factors elsewhere.

Extensive variety testing of standard corn varieties at New Brunswick, New Jersey, for a 3-year period, has indicated that varieties introduced into that state from other corn-growing states to the north, south, and west were almost invariably inferior to well-adapted local strains. The average yield of 61 standard varieties from 14 other states was 19.2% less than that of adapted strains, when the value of both grain and stover was included. In grain yield alone, the introduced varieties averaged 27.8% less than that of adapted strains. Only two of the introduced varieties equaled the yield of adapted varieties, and none exceeded the best local strains. Certain of the so-called silage varieties produced more dry matter per acre than the better local strains, but they yielded considerably less actual feed per acre because of the greatly inferior ear development of the southern varieties.

It was found in cooperative tests with farmers that many local strains were poorly adapted, either because of the recent introduction of seed from other states or because of seed selection methods which ran contrary to natural selection of adapted types. The detailed results of these tests are presented in New Jersey Agricultural Experiment Station Bulletin 537. Although the number of varieties tested yearly since 1930 has been reduced, the later results have substantiated the earlier findings.

Since New Jersey is not greatly separated from Connecticut in distance, nor markedly different in climate and soil, the results of variety testing in the two states should show similar trends. The trials of corn varieties in New Jersey do not support the general rule proposed by Jones and Huntington which states that, "Corn may be moved from a less favorable to a more favorable climatic region without loss of productive capacity, and usually with distinct gain." On the contrary, the figures in Table 1 from the New Jersey experiments support the principle that varieties grown and properly selected in a given environment normally exhibit greater adaptation to that particular complex of conditions than varieties introduced from a region with different conditions of soil, climate, and pests.

In making comparisons with introduced varieties, a great deal depends on the particular local strains used as the standard. In a state where comparatively little attention has been given to selection of adapted strains, many of those grown by farmers are low

TABLE 1.—*Yields of standard varieties of corn when grown at New Brunswick, N. J., 1928–30, inclusive.*

Variety	Source	Cured stover per acre, lbs.	Shelled grain per acre, bu.
Reid's Yellow Dent	New Jersey	9,083	62.2
Reid's Yellow Dent	Illinois	9,411	51.3
Reid's Yellow Dent	Indiana	10,189	43.1
Reid's Yellow Dent	Iowa	6,822	49.0
Reid's Yellow Dent	Kansas	9,502	47.1
Reid's Yellow Dent	Nebraska	7,021	48.7
Lancaster Surecrop	New Jersey	9,126	55.5
Lancaster Surecrop	Pennsylvania	7,634	48.1
Eureka Ensilage	Virginia	12,532	33.2
Cocke's Prolific	Virginia	9,765	33.8
Cocke's Prolific	Mississippi	9,853	41.5

in productivity. In all fairness, comparisons should be made between varieties that are well suited to the localities in which they originate.

TABLE 2.—*Variability of local strains in New Jersey.*

Variety	Cured stover per acre, lbs.	Shelled grain per acre, bu.
Tests Conducted in South Jersey, 1928–31, Inc.		
Hulsart Yellow Dent	3,915	32.7
Local Yellow—A	3,445	26.4
Local Yellow—B	4,406	21.9
Local Yellow—C	4,083	19.5
Tests Conducted in North Jersey, 1928–31, Inc.		
Mercer White Cap	5,587	55.1
Local White Cap—A	6,037	51.0
Local White Cap—B	3,909	42.8
Local Yellow—C	3,734	41.9

The named varieties in Table 2 are also local strains, but they have been produced by growers who consistently practice desirable methods of selection. The other varieties had either been introduced from other states within a 3- or 4-year period prior to testing, or had been selected for characters known to be antagonistic to high yields, such as excessive kernel depth and roughness, large diameter of ear, and very tall stalks.

Before adopting the principles laid down by Jones and Huntington, it would be desirable to determine the degree to which these principles explain the results of variety trials throughout the corn-growing region. The results of adaptation tests with corn varieties in such states as Kansas and Nebraska apparently do not harmonize with these principles. For satisfactory application to New Jersey, some important changes in concept certainly seem necessary.—H. B. SPRAGUE, *New Jersey Agricultural Experiment Station, New Brunswick, N. J.*

FURTHER COMMENTS ON ADAPTATION OF CORN TO CLIMATE

DARWIN once said that "the thing that disgusted him most was that two people could take the same facts and arrive at opposite conclusions." This seems to have happened to Sprague and ourselves. He doubts our thesis that "corn may be moved from a less favorable to a more favorable climatic region without loss of productive capacity, and usually with distinct gain, provided the length of the growing season permits satisfactory maturity." We think that his original data in Bulletin 537 of the New Jersey Agricultural Experiment Station support this thesis, or at least do not contradict it. From among the 14 New Jersey varieties which were tested by Sprague and his co-workers, they selected the 6 with the highest yield and compared them with 61 varieties which they had brought in from 14 other states. This is an unfair comparison in several ways. In the first place, four of the six selected New Jersey varieties originated outside that state, and one of the others appears to be a western variety grown locally and renamed, even though all had been selected in New Jersey long enough to be well adapted to local conditions.

In the second place, although the best six New Jersey varieties were chosen, no corresponding selection was made among the 61 varieties from other states, and some varieties known to be of low yield have been used. A third reason for questioning Sprague's use of his data is that portions of the 14 states from which seed was brought to New Jersey, for example Pennsylvania and the parts of the states from Ohio to Iowa from which the seed was presumably obtained, are climatically about on a par with northern New Jersey or even better. Hence, according to our theory, the yield from such states would remain about the same when seed was brought to New Jersey. The facts bear this out, for according to New Jersey Bulletin 537, the average yield of all varieties of corn raised in New Jersey from Illinois seed was 52.9 bushels, from Ohio seed 51.7 bushels, and from New Jersey seed 50.8 bushels. If we select only the highest yielding varieties, the Illinois seed is again first with 66.4 bushels as compared with 62.2 bushels for New Jersey. Two hybrid varieties from Iowa yielded 69.0 and 62.9 bushels, respectively, but part of this high yield may have been due to hybrid vigor. Other western and more southern seed failed to yield as much as New Jersey varieties by a considerable margin.

Turning now to the value of corn as forage, in New Jersey Bulletin 537, 4.5 pounds of stover is taken as being equal to 1 pound of grain in feeding value, and on this basis the relative amounts of feed produced by different varieties are calculated. Taking the averages of all varieties and classifying the results according to where the seed was obtained, the order is as follows: Kansas, 95.1; Illinois, 94.4; Ohio, 88.7; and New Jersey, 87.8. It is rather surprising that the seed from southern Pennsylvania and from states farther south does not make so good a showing. If determinations of total dry matter were made, varieties from these sources would probably stand relatively higher as they do in Connecticut. It should be noted in this

connection that the difference in yield of corn between the central corn-growing states and New Jersey is much less than between those same states and Connecticut.

Sprague's second table seems to us irrelevant to the specific point at issue, although it is interesting and valuable from other viewpoints. The superiority of some varieties points to a conclusion which we would be the last to question, namely, that corn can be improved by proper selection. The great contrast between the yields in northern New Jersey—42 to 55 bushels per acre—and in southern New Jersey—20 to 33 bushels—points to another conclusion on which we insist strongly, *viz.*, that corn responds with peculiar readiness to variations in climate. The data on which our article was based show that a rise of only a very few degrees above the optimum temperature greatly reduces the yield of corn. Northern New Jersey is about 2 degrees too warm for the best results and southern New Jersey about 4 degrees. This seems like very little, and of course, differences in soil and so forth must be taken into account. Nevertheless, in the critical periods in the development of a corn plant, a very small rise in temperature does great damage. Some of the highest yielding New Jersey varieties used in Sprague's comparisons were moved from the southern to the northern part of the state, and this change is probably greater climatically than the change from some of the western states of the same or more northerly latitude into New Jersey.

None of the figures that Sprague has brought forth as well as those which we have extracted from New Jersey Bulletin 537 have any critical bearing on the point at issue, which is, Do varieties of corn perform as well as in their place of origin or even increase in yield when changed from a less favorable to a more favorable climatic region? To answer this question we must know also the yields of the varieties in their native environment.

Part of our own data are also inconclusive in that they do not show the yields of the introduced varieties in their native environment. More information of this nature is needed. Seasonal conditions vary widely in different places so that yields would have to be based on long-time averages. The results from sweet corn are somewhat more dependable, since with this material, varieties have been moved in both directions with results that are consistent with our conclusions. Take, for example, Golden Cross Bantam which originated in Indiana. As a general rule the plants grow taller and produce larger ears in Connecticut and in Massachusetts than they do in the central states. On the other hand, Redgreen, a Connecticut product, that is used for canning in central New York and yields abundantly there, has rarely produced a satisfactory crop in any of the midwestern states but has produced more marketable ears per acre in cool areas, such as Nevada, Idaho, and Washington, than in Connecticut.—DONALD F. JONES and ELLSWORTH HUNTINGTON, *Connecticut Agricultural Experiment Station, New Haven, Conn.*

AGRONOMIC AFFAIRS

A TRIBUTE TO DOCTOR LIPMAN

THE advisory staff of SOIL SCIENCE has dedicated Volume 40 of that journal, and particularly the first number of the volume, to Dr. J. G. Lipman, founder and Editor-in-Chief for twenty years, in honor of his editorship and his long-continued service to soil science and agriculture. Dr. Lipman is on sabbatic leave this year, thus affording the editorial staff an excellent opportunity to honor their chief.

Among the special features appearing in the July number of SOIL SCIENCE are the following: A brief biographical sketch of Dr. Lipman; "Jacob G. Lipman and Soil Science," by E. J. Russell; "Jacob G. Lipman as an Investigator," by Selman A. Waksman; "Jacob G. Lipman and New Jersey Agriculture," by A. W. Blair; and "Jacob G. Lipman as Teacher and Director of Research," by Robert V. Allison.

MEETING OF WESTERN SECTION OF SOCIETY

THE nineteenth annual meeting of the Western Section of the Society met at Pendleton, Ore., June 18 to 20, with 62 agronomists in attendance, representing seven states and the U. S. Dept. of Agriculture. A total of 28 papers was presented at five sessions, with one afternoon devoted to a tour of inspection of the Pendleton field station and the Wildhorse soil erosion project. Details regarding the papers presented on the formal program may be obtained from the Secretary of the Section.

At the business meeting it was voted to hold the 1936 meeting jointly at the Washington State College, Pullman, Wash., and the University of Idaho, Moscow, Idaho. Dr. R. S. Hawkins of the University of Arizona was elected President of the Section, succeeding Prof. B. A. Madson of the University of California; and Prof. E. G. Schafer of Washington State College was named Secretary, succeeding J. Foster Martin of Pendleton, Ore.

NEWS ITEMS

ROBERT E. FORE has been awarded the degree of Doctor of Philosophy by the University of Illinois, the major subject of his graduate studies being in plant breeding.

IT WAS voted at the recent meeting of the Corn Belt Section of the Society at St. Paul, Minn., to hold the next annual meeting of the Section at the University of Illinois.

WORD has been received of the death of Mr. S. H. Essary, Botanist at the Tennessee Agricultural Experiment Station and for many years a member of the Society.

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A SEARCH FOR FACTORS DETERMINING WINTER HARDINESS IN ALFALFA[1]

C. R. Megee[2]

IN the northern part of the United States winter killing of alfalfa is often prevalent and the seeding of winter hardy strains is of paramount importance in maintaining satisfactory stands. Field tests to determine the relative winter hardiness of the various strains of alfalfa have contributed much toward enabling Michigan to become the second highest state in the acreage of alfalfa in the United States. The hardy strains of alfalfa, such as Hardigan and Grimm, are usually able to withstand low temperatures without winter killing, while the non-hardy strains, such as Arizona Common and Hairy Peruvian, often are killed the first winter. There are many strains occupying an intermediate position of winter hardiness between these extremes.

During the past 15 years the writer (14)[3] has conducted many field tests to determine the relative winter hardiness of the various strains of alfalfa of the United States and many foreign countries. In order for a field test to reach a high degree of dependability it is necessary that it extend over a period of from 4 to 8 years and this involves a serious delay as well as considerable expense in conducting the test. While such tests have been of much value in determining the relative winter hardiness of the various strains of alfalfa, they have in no way explained the phenomenon of winter hardiness.

Increase in colloid content and osmotic pressure of root sap and decrease in moisture content of alfalfa tissue have been suggested as an explanation for winter hardiness. Should it be possible to locate some one or more factors definitely correlated with winter hardiness that could readily be determined in the laboratory, this problem of the agronomist would be greatly simplified.

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[1]Contribution from the Soils Section, Michigan State College, East Lansing, Mich. Taken from a thesis submitted to the Faculty of Michigan State College in partial fulfillment of the requirement for the degree of doctor of philosophy. Published as journal article No. 220 n. s. of the Michigan Agricultural Experiment Station. Received for publication June 25, 1935.

[2]Associate Professor. The author expresses his appreciation to members of the Soils Department and to Prof. H. C. Rather and Dr. R. P. Hubbard of the Farm Crops and Botany Departments, respectively, for helpful suggestions during the progress of the experimental work and preparation of the manuscript.

[3]Figures in parenthesis refer to "Literature Cited," p. 698.

The object of this paper is to present data on the relationship between winter hardiness of alfalfa and various properties of alfalfa root tissue as measured by electrical conductivity, moisture equivalent, swelling, heat of wetting of oven-dry tissue, respiration, freezing point depression, moisture content, and the rate of loss of moisture. Should any of the above factors prove to be directly correlated with winter hardiness, the fact would be an important step in determining and possibly explaining the phenomenon of winter hardiness.

It is generally recognized that damage to plants may result from winter injury due to several causes, such as low temperature, heaving of soil and plants by the building up of layers of ice in the soil, suffocation under an ice crust, and the desiccation of plant tissues due to dry winds. In this paper only the first form, winter injury due to low temperature, is considered. In the experiments here reported, the other three forms of winter injury were almost, if not entirely, absent.

REVIEW OF LITERATURE

No attempt will be made to review the voluminous literature on the subject of winter hardiness. Harvey (12) gives a very complete bibliography on the low temperature relations of plants. Chandler (5), Dexter, *et al.* (6), Graber, *et al.* (10), Gortner (9), Harvey (11), Maximov (13), Newton (15), and Rosa (16) not only give their views but also have reviewed the work of other investigators. Dexter, *et al.* (6), upon mentioning the work of other investigators states: "It may be briefly stated that most, if not all, of the theories of winter hardiness are built around the idea of the water relation of the plants and that structural, osmotic, or colloidal protection from water withdrawal or ice formation form the basis of explanation for individual or varietal differences in hardiness."

MATERIAL USED

Three strains of alfalfa of known winter hardiness, Hardigan, Utah Common and Arizona Common, were selected for these experiments from among a large number of strains representing most of the seed-producing sections of the world. Field tests of these strains for winter hardiness were previously conducted by the writer over a period of 8 years. Plats seeded in 1921 were continued until 1929. Other plats seeded in 1922, 1923, and 1924 were continued for periods ranging from 3 to 5 years. Table 1 shows the comparative winter hardiness of these three strains under Michigan conditions.

TABLE 1.—*Comparative winter hardiness as indicated by yield of Hardigan, Utah Common, and Arizona Common alfalfas at East Lansing, Michigan.*

Variety	Yields of hay expressed in per cent of Hardigan yields									Average yield per acre, tons
	1922	1923	1924	1925	1926	1927	1928	1929	Average	
Hardigan...	100	100	100	100	100	100	100	100	100	4.8
Utah Common......	93.7	82.9	90.7	65.9	50.2	47.0	64.6	57.6	69.1	3.3
Arizona Common	63.3	10.8	19.6	11.7	21.9	0.0	0.0	0.0	15.9	0.8

Hardigan is a variegated strain of alfalfa developed at the Michigan Agricultural Experiment Station and is very winter hardy under Michigan conditions. Utah Common is a strain of only medium winter hardiness and has been grown for many years in the alfalfa seed-producing section of the Uinta Basin of Utah. Arizona Common is from the Yuma Valley of southwestern Arizona and is one of the least winter hardy strains of alfalfa.

It has been observed that alfalfa plants sometimes live through the winter entirely devoid of leaves. In view of this observation the material used in the laboratory tests consisted of the root and a portion of the crown, the top being removed just above the lower crown buds. Although containing a portion of the crown, this material is referred to as the root.

The roots used were of the first season's growth and were grown on a Hillsdale sandy loam soil. Roots were used from both fertilized and unfertilized plats. The amounts of superphosphate and muriate of potash necessary to apply to the soil in order to have a good supply of available phosphorus and potassium present as determined by the Spurway method (17) were found to be equivalent to the nutrients in an application of 2,400 pounds per acre of an 0–8–24 fertilizer. These materials were applied to a series of plats on May 29 and worked in as the soil was prepared for seeding which was done June 8. On September 4 a like application was made as a top dressing on another series of plats. On the same date an application of 500 pounds per acre of nitrate of soda as a top dressing was made on a third series of plats. The fertilized plats were 25 x 300 feet and the varieties of alfalfa were seeded in quadruplicate plats 25 x 330 feet running across the fertilized and unfertilized plats. This arrangement provided roots of both hardy and non-hardy alfalfas grown on fertilized and unfertilized soil.

EXPERIMENTAL RESULTS

RELATION BETWEEN WINTER HARDINESS AND LIBERATION OF ELECTROLYTES BY ALFALFA ROOT TISSUE EXPOSED TO LOW TEMPERATURE

It is a matter of frequent observation that as the living protoplasm of a cell is injured it becomes more permeable and the electrolytes pass out of the cell. As the injury becomes more intense the permeability increases and additional electrolytes are liberated. To determine the amount of electrolytes liberated when alfalfa roots were submitted to low temperature, electrical conductivity determinations were made on water extracts of roots of hardy and non-hardy alfalfas collected from fertilized and unfertilized plats. The method suggested by Dexter, *et al.* (6) was used.

Extreme care must be exercised in preparing alfalfa field material for electrical conductivity tests. Hardigan, though one of the most uniform strains of alfalfa, is not a pure line selection owing to its method of pollination. Consequently, some variations will be found in the winter hardiness of different individual plants. Also, an entirely uniform soil cannot be secured for field work. To eliminate these variations in so far as possible, plants were selected from various parts of the plat and after thorough washing and removal of the external moisture, the roots were cut into ¾ inch pieces and the pieces thoroughly mixed so that the 10-gram sample used would represent the plat as a whole.

The samples were then placed in Pyrex glass tubes and the tubes held in alcohol slush in a cold chamber. The alcohol slush was found to be very efficient in maintaining the material at a constant temperature, variations seldom exceeding 1°. Samples taken in October and November were frozen at —9° C for 4 hours, but as the season advanced it was found necessary to freeze later samplings for a longer period, or at a lower temperature. At the end of the freezing period 75 cc of distilled water were added and the tubes placed in a water bath maintained at 2° C. Exosmosis was allowed to proceed for 20 hours, at the end of which time conductivity readings were made by means of a Wheatstone bridge. The Wheatstone bridge readings are expressed in specific conductivity ($x\ 10^{-6}$) in reciprocal ohms (mhos) per gram of dry matter. Before making the reading each tube was inverted three times to secure an equal distribution of the electrolytes through the solution. Student's method was applied to data from triplicate samples and in most instances differences greater than 8% were found to be significant.

Electrical conductivity tests were made on samples of roots taken October 16, 1933, from the Hardigan and Arizona Common varieties from plats receiving no fertilizer treatment and from plats receiving each of the fertilizer treatments. No varietal or plat differences were found. Hardening had not developed to a point where a distinction could be made between hardy and non-hardy alfalfas.

On November 23, 1933, the test was repeated. The roots were frozen 4 hours at —9° C and 20 hours were allowed for exosmosis.

TABLE 2.—*Effect of freezing on the liberation of electrolytes from roots of hardy and non-hardy alfalfas grown on fertilized and unfertilized soil, test made November 23, 1933.*

Fertilizer treatment	Portion of root used	Mhos per gram of dry matter		Difference, %
		Hardigan	Arizona Common	
None	Upper 5 inches	37.0	53.7	45.1
	Lower and fibrous	61.5	70.5	14.6
0-8-24....... Sept. 4	Upper 5 inches	50.5	64.5	27.7
	Lower and fibrous	75.1	77.5	3.1

The results, presented in Table 2, show that the Hardigan roots were much more resistant to low temperature than were those of Arizona Common. Resistance to damage from low temperature developed most rapidly in the upper portion of the tap root, while it was delayed at lower depths and in the small lateral and hair roots. Heavy applications of an 0-8-24 fertilizer on September 4 caused resistance to damage by cold to develop slowly. No difference was found in the average air-dried weight of hardy and non-hardy alfalfa roots, consequently the weight of the root is not a factor in winter hardiness.

In contrast to the results presented above, no differences were found in the winter hardiness of alfalfa roots from the plats receiving no fertilizer, the roots from plats receiving fertilizer on May 29,

and the roots from plats receiving nitrate of soda on September 4.

The electrical conductivity tests were repeated on samples taken December 16 and December 18. The relationship of Hardigan to Arizona Common and the effects of different soil treatments had not changed. Somewhat more resistance to liberation of solubles through freezing had developed, but just how much could not be determined because the roots dug December 16 were frozen for 15 hours at —9° C and those dug December 18 were frozen for 6 hours at —15° C.

Another lot of Hardigan roots was dug January 15, the object of this test being to determine the relative winter hardiness of the roots from plats receiving no fertilizer treatment with those from plats receiving 2,400 pounds of 0-8-24 on September 4, and also to determine the relative amounts of electrolytes liberated when the roots were not cut, when cut into ¾ inch lengths and into ⅜ inch lengths, and when ground. The roots were frozen 15 hours at —9° C and 20 hours were allowed for exosmosis at 2° C. After the determinations were made the samples were boiled for 15 minutes, 20 hours allowed for exosmosis at 2° C, and the electrical conductivity redetermined.

TABLE 3.—*The effect of freezing upon the liberation of electrolytes from roots of hardy alfalfa when grown on fertilized and unfertilized soil and when tap and fibrous roots were cut at different lengths and when ground, test made January 15, 1934.*

Part of roots used	Size of pieces	Mhos per gram of dry matter				Difference, %	
		No soil treatment		Fertilized Sept. 4			
		Frozen	Frozen and boiled	Frozen	Frozen and boiled	Frozen	Boiled
Tap	Uncut	25.2	121.3	30.5	125.0	21.0	3.0
Tap	¾ in.	28.7	137.2	34.7	139.5	20.9	1.6
Tap	⅜ in.	34.3	143.6	41.2	144.5	20.1	0.6
Tap	Ground	52.8	151.5	60.5	153.2	14.5	1.7
Fibrous	¼ in.	49.0	151.6	54.7	155.2	11.1	2.3
Fibrous	Ground	63.4	156.2	68.6	158.0	8.2	1.1

The results given in Tables 2 and 3 show that the roots from plats receiving an 0-8-24 fertilizer on September 4 hardened less rapidly during November than the roots from the other plats, but during late December and January they hardened more rapidly. The injurious effect of low temperature upon alfalfa roots receiving fertilizer during September would depend largely upon whether the soil temperature was low during the fall or whether it was low during the winter. During 1933-34 the soil temperature was not low until after January 15 and all plats of Hardigan came through with very little, if any, injury. None of the Arizona plats had been injured to any appreciable extent prior to January 15, but winter killed 99% by spring. The test ran January 15 showed that all plats of alfalfa had made a considerable increase in winter hardiness since November 23. This increase was greater than is shown by comparing the figures

in Tables 2 and 3, since the roots dug November 25 were frozen 4 hours at —9° C, while those dug January 15 were frozen 15 hours at —9° C and the latter liberated less electrolytes.

Data in Table 3 also show that grinding tap roots and grinding and cutting fibrous roots failed to bring out differences in winter hardiness by the electrical conductivity method to the extent that was brought out with uncut roots and with tap roots cut in lengths of ¾ inch and ⅜ inch. The results secured after boiling show that the greater liberation of electrolytes from the roots from plats receiving fertilizer on September 4 was due to less hardening and not to an excess of salt stored in the roots. The results secured when the tests were repeated during the season of 1934–35 were the same, except that the amount of electrolytes released after boiling was somewhat more variable, likely due to the extreme drought of the summer of 1934. This fact did not change the relationship of one variety to another or of one plat treatment to another in comparison with the results of 1933–34. The electrical conductivity test was found to be valuable in determining the relative winter hardiness of different alfalfas.

PARTIAL CHEMICAL ANALYSIS OF HARDY AND NON-HARDY ALFALFA ROOTS

A chemical analysis[4] of the roots was made to determine whether there was a relationship between winter hardiness and the chemical composition of the roots. The results of the chemical analysis are shown in Table 4.

The chemical analysis of the alfalfa roots afforded no positive indication concerning factors causing winter hardiness. There are, however, some consistent differences in the protein and crude fiber content of the Hardigan and Arizona Common roots. On December 20, the date when a certain degree of winter hardiness had developed, the protein content of the Hardigan roots was higher than that of the Arizona Common roots and the increase in protein content at this date over that of October 16 was greater in the case of Hardigan than for Arizona Common. The crude fiber content of the Hardigan alfalfa was lower in all cases than that of the Arizona Common at both dates of sampling and the crude fiber content of Arizona Common increased markedly over that of Hardigan between the two dates. The sum of the protein and nitrogen-free extract content of Hardigan was slightly but consistently greater than that of Arizona Common.

MOISTURE CONTENT OF ROOTS OF HARDY AND NON-HARDY ALFALFAS

The moisture content of many winter hardy plants decreases as the fall and winter seasons advance. In order to determine the relationship between winter hardiness and moisture content, the amount of moisture in the roots of Hardigan and Arizona Common strains of al-

[4]The writer hereby acknowledges the assistance of the Chemistry Section of the Michigan Agricultural Experiment Station in determining the chemical analysis.

TABLE 4.—*A comparison of partial chemical analysis of roots of hardy and non-hardy alfalfas.*

Variety	Treatment	H_2O %	Protein %	Ash %	Fat %	Crude fiber %	Nitrogen-free extract %	CHO %
		Roots Dug October 16, 1934						
Hardigan	None	7.39	15.60	2.11	0.66	16.68	57.56	74.24
Arizona Com	None	7 26	14.99	2.61	0.77	18.04	56.33	74.37
Hardigan	0–8–24,	7.15	14.57	3.32	0.63	14.34	59.99	74.35
Arizona Com.	May 29	7.22	14.63	2.04	0.48	17.02	58.69	75.71
Hardigan	0–8–24,	7.22	15.16	2.63	0.69	14.60	59.70	74.30
Arizona Com.	Sept. 4	7.04	14.29	2.80	0.39	17.33	58.15	75.48
Average .		—	14.87	2.58	0.60	16.33	58.40	74.74
		Roots Dug December 20, 1934						
Hardigan	None	5.27	19.08	2.23	1.76	23.39	48.27	71.66
Utah Com.	None	6.56	17.71	2.25	1.59	21.19	50.70	71.89
Arizona Com.	None	5.92	16.34	2.17	1.47	25.68	48.42	74.10
Hardigan	0–8–24,	5.63	17.81	2.87	1.32	18.30	54.57	72.37
Utah Com.	May 29	5 98	17.50	2.53	0.97	19.02	53.65	72.67
Arizona Com		6.03	15.71	2.63	1.32	21.25	53.41	74.66
Hardigan	0–8–24,	5.46	17.98	3.16	1.99	19.74	51.67	71.41
Arizona Com.	Sept 4	5.76	16.41	2.85	1.28	23.84	49.86	73.70
Average		—	17 31	2 59	1.46	21.55	51.32	72.80

falfa was determined at intervals during the fall and winter months. An electrically controlled oven maintained at 90° C was used for this purpose. The results are presented in Table 5.

TABLE 5.—*The moisture content of the roots of hardy and non-hardy alfalfas from October to February.*

Date roots were dug, 1934–35	Moisture %	
	Hardigan	Arizona Common
October 24	66.7	67.0
Nov. 19	60.0	61.3
Dec 22	62.9	63.0
Jan. 1	62.4	62.3
Jan. 21	64.0	64.0
Feb. 6	68.4	68.5
Feb. 20	68.2	66.7
Growing	76.4	76.8
Average	66.1	66.2

The results show that no varietal differences in moisture eontent of the roots existed either during the fall or the winter months nor when the roots were in a growing condition. Hardened roots of winter hardy strains of alfalfa were low in moisture, as were the roots of the non-hardy alfalfas. Consequently, there is no significant correlation between winter hardiness and moisture content.

RATE OF LOSS OF MOISTURE FROM ROOTS OF HARDY AND NON-HARDY ALFALFAS

Protection against water withdrawal has been advanced as of importance in preventing winter injury. In case this is true Hardigan should release its moisture more slowly at low temperatures than would the less winter hardy Arizona Common. The relative loss of moisture of the roots of both Hardigan and Arizona Common was determined. Hardened living roots were dug February 20 and slowly reduced in moisture content in desiccators held at 2° C and at —9° C. The samples were weighed daily and the daily loss of moisture calculated. The results are shown in Table 6.

TABLE 6.—*The rate of loss of moisture from roots of hardy and non-hardy alfalfas held at 2° C and —9° C.*

No. days	Held at 2° C				Held at —9° C			
	Total loss %		Loss per day %		Total loss %		Loss per day %	
	Hardigan	Arizona Com.	Hardigan	Arizona Com.	Hardigan	Arizona Com.	Hardigan	Arizona Com.
1.....	23.0	21.0	23.0	21.0	14.0	18.2	14.0	18.2
2.....	33.8	32.4	10.8	11.4	25.6	27.0	11.6	8.8
3.....	48.2	45.8	14.4	13.4	35.6	38.8	10.0	11.8
4.....	59.0	57.4	10.8	11.6	43.8	48.0	8.2	9.2
5.....	62.4	62.6	3.4	5.2	47.6	52.4	3.8	4.4
6.....	64.0	65.4	1.6	2.8	48.6	53.4	1.0	1.0
7.....	64.8	66.2	0.8	0.8	60.0	62.4	11.4	9.0
8.....	65.0	66.4	0.2	0.2	63.0	63.8	3.0	1.4
9	65.4	66.8	0.4	0.4	65.0	64.6	2.0	0.8
10.....	65.6	66.8	0.2	0.0	66.8	65.2	1.8	0.6
11.....	66.0	67.4	0.4	0.6	67.4	66.0	0.6	0.8
12.....	68.2	69.2	2.2	1.8	68.6	66.0	1.2	0.0

On the eighth day samples of roots of both Hardigan and Arizona Common were removed from the desiccator held at 2° C. The roots were transplanted into flower pots filled with sandy soil and held at favorable conditions for growth. Growth was resumed, although 65% of the original weight of the roots had been lost due to the loss of moisture. The results show that both hardy and non-hardy alfalfa roots can withstand a heavy loss of moisture without being severely injured. The results also show that there is no consistent difference between hardy and non-hardy alfalfas in either the rate of loss of moisture or total moisture lost, and that the loss of moisture was not correlated with winter hardiness.

RELATIVE RATE OF RESPIRATION OF ROOTS OF HARDY AND NON-HARDY ALFALFAS

Respiration is the process of energy release in the living cell. The end products of aerobic respiration are CO_2 and water and the intensity of respiration may be determined by measuring the amount of CO_2 liberated over a given period of time. Plants become dormant as the fall and winter seasons advance and the process of energy release slows down.

In order to determine the relationship between winter hardiness and the rate of energy release, the relative rate of respiration of hardy and non-hardy alfalfas was determined. The roots were placed in 500-cc Erlemeyer flasks fitted with rubber stoppers and in-take and out-let tubes. The tubes were kept stoppered except when connected to the train for CO_2 determinations. The train was set up as follows: Air pump, potassium hydroxide solution, ascarite, phosphoric anhydride, concentrated sulfuric acid, sample, distilled water, and potassium hydroxide. Duplicate 20-gram samples were used. The apparatus was checked repeatedly for leaks. Each sample was connected into the train for 5 minutes, a previous test having shown that the air was completely changed in 2 minutes. The results are shown in Table 7.

TABLE 7.—*The relative rate of respiration of hardy and non-hardy alfalfa roots held at different temperatures.*

Condition of roots	Temperature, °C	Average daily liberation of CO_2, grams	
		Hardigan	Arizona Common
Not hardened	21°	0.1151	0.1185
Not hardened	10°	0.0163	0.0157
Not hardened	2°	0.0139	0.0129
Hardened	15°	0.0400	0.0384
Hardened	2°	0.0145	0.0140

The results show no difference in the rate of respiration between roots of hardy and non-hardy alfalfas.

RELATION BETWEEN WINTER HARDINESS AND PHYSICO-CHEMICAL BEHAVIOR OF COLLOIDAL MATERIAL IN ALFALFA ROOTS

The great importance of colloidal materials in the functioning of living matter immediately raises the question of the relationship between winter hardiness and the physico-chemical nature of the colloidal material in hardy and non-hardy alfalfas. Moisture equivalent (3), swelling (4), and heat of wetting (2) afford good indices of physico-chemical differences of colloidal materials. The above-mentioned indices were used to study the relationship between winter hardiness and the nature of the colloidal materials present in hardy and non-hardy alfalfas.

Roots of the hardy and non-hardy alfalfas from plats receiving the various fertilizer treatments were dug at dates ranging from October 21 to December 17. These roots were thoroughly washed, dried at air temperature, and ground to a very fine meal. Each sample was thoroughly mixed to facilitate sampling.

The moisture equivalent of colloidal material of the roots of hardy and non-hardy alfalfas.—The moisture equivalent was determined as follows: A Büchner funnel fitted with a filter paper was filled with ground roots and the funnel tapped gently 20 times to secure a uniform settling of the material. The funnel was then placed in a beaker of water for 4 hours and the excess water removed by means of suction filtration for 15 minutes. The material was then removed from

the filter, weighed, and placed in an electrically controlled oven held at 90° C for 16 hours. The material was then weighed and the amount of water adsorbed was calculated. The results are presented in Table 8.

TABLE 8.—*The moisture equivalent of the colloidal material in roots of hardy and non-hardy alfalfas.*

Date roots were dug, 1934	Fertilizer treatment		Moisture equivalent %		
	Kind	Date applied, 1934	Hardigan	Utah Common	Arizona Common
Oct. 21	0-8-24	May 29	182	—	172
Nov. 6	None	———	200	—	199
Nov. 6	0-8-24	May 29	187	—	180
Nov. 6	0-8-24	Sept. 4	201	—	194
Nov. 6	Nitrate of soda	Sept. 4	207	—	198
Nov. 24	None	———	219	—	222
Nov. 24	0-8-24	May 29	221	—	215
Dec. 17	None	———	263	261	265
Dec. 17	0-8-24	May 29	266	262	252
Dec. 17	0-8-24	Sept. 4	256	264	269
Dec. 17	Nitrate of soda	Sept. 4	260	265	259

The results show a marked change from late October into December in the nature of the colloidal material present in the roots of both hardy and non-hardy alfalfas. Winter hardiness is not correlated with this change in the nature of the colloidal material since the change takes place to the same extent in both hardy and non-hardy alfalfas.

The swelling of colloidal material in the roots of hardy and non-hardy alfalfas.—A 5-gram sample of material was weighed out and placed in a 50-cc graduated cylinder which was then filled with distilled water to the 50 cc mark. The material was stirred to secure uniform wetting, shaken, and enough water added to fill again to the 50 cc mark. Care was exercised in securing cylinders of the same diameter and calibration. The cylinders were then placed in a chamber maintained at 10° C for 16 hours, at the end of which time reading was made. The results are shown in Table 9.

The results show a change from October 21 to December 17 in the physico-chemical nature of the colloidal material present in the roots. This change is shown by the increase in the swelling of the colloidal material. The seasonal change from October 21 to December 17 was the same for the non-hardy as for the hardy alfalfas. Fertilizer treatments did not influence the change. These results support those secured by the moisture equivalent index, in that winter hardiness is not a direct result of certain physico-chemical changes in the colloidal material of the alfalfa roots.

The heat of wetting of colloidal material in the roots of hardy and non-hardy alfalfas.—A 20-gram sample of air-dried material was placed in a wide glass tube and allowed to dry in an electrically heated oven at a temperature of 90° C for 16 hours. The tube was then removed from the oven, closed tightly with a rubber stopper, and placed on the desk close to the calorimeter, a liter of distilled water, and another sample of material, so that all samples and equip-

TABLE 9.—*The swelling of the colloidal material of the roots of hardy and non-hardy alfalfas during the fall and early winter months.*

Date roots were dug, 1934	Fertilizer treatment		Swelling in cc		
	Kind	Date applied, 1934	Hardigan	Utah Common	Arizona Common
Oct. 21	0-8-24	Sept. 4	24.0	—	24.5
Nov. 6	None	—	27.0	—	26.5
Nov. 6	0-8-24	May 29	26.5	—	27.0
Nov. 6	0-8-24	Sept. 4	27.0	—	27.0
Nov. 6	Nitrate of soda	Sept. 4	27.5	—	26.0
Nov. 24	None	—	33.5	—	33.0
Nov. 24	0-8-24	May 29	33.0	—	31.0
Dec. 17	None	—	34.0	34.0	34.0
Dec. 17	0-8-24	May 29	33.5	34.0	33.0
Dec. 17	0-8-24	Sept. 4	35.0	36.0	35.0
Dec. 17	Nitrate of soda	Sept. 4	34.0	33.0	35.0
Average of roots dug Dec. 17			34.1	34.2	34.2

ment would reach the same temperature. After a uniform temperature was established, 100 cc of water were placed in the calorimeter and the heat of wetting of the plant material ascertained (2). The tube was handled with a heavy cloth so that heat would not be imparted to the material. Great care was taken to have the calorimeter, the water, and the material at the same temperature, which was that of the room. The results are given in Table 10.

TABLE 10.—*The heat of wetting of colloidal material in the roots of hardy and non-hardy alfalfas.*

Date roots were dug, 1934	Fertilizer treatment		Heat of wetting, calories	
	Kind	Date applied, 1934	Hardigan	Arizona Common
Nov. 1	None	—	100.0	101.8
Nov. 1	0-8-24½	May 29	103.0	100.0
Dec. 17	None	—	131.0	131.2
Dec. 17	0-8-24	May 29	129.3	128.1

A change in the physico-chemical nature of the colloidal material from November 1 to December 17 was shown by the increase in the heat of wetting. The change was similar for both hardy and non-hardy alfalfas. These results support those secured by both moisture equivalent and swelling determinations. Neither moisture equivalent, swelling, nor heat of wetting were found to be an index of winter hardiness in alfalfa.

SOLUBLE MATERIAL IN ROOTS OF HARDY AND NON-HARDY ALFALFAS

The concentration of the material in solution in the plant cell influences substantially the intake, outgo, and translocation of materials in plants.

The freezing point method was used to determine the relation between winter hardiness and the quantity of soluble material in roots

of hardy and non-hardy alfalfas. A 5-gram sample of air-dried root material was placed in the freezing tube and 20 cc of distilled water were added. The contents of the tube was stirred thoroughly and allowed to stand for 20 minutes. The freezing point was then determined (1), making use of a freezing bath with a temperature of —2.5° C. The contents of the tube was super-cooled about 1 degree before solidification was induced. The results are given in Table 11.

TABLE 11.—*Freezing point depression of roots of hardy and non-hardy alfalfas during October, November, and December.*

Date roots were dug, 1934	Fertilizer treatment		Freezing point depression, °C		
	Kind	Date applied, 1934	Hardigan	Utah Common	Arizona Common
Oct. 21	0-8-24	Sept. 4	—0.56°	—	—0.56°
Nov. 6	None	—	—0.61°	—	—0.60°
Nov. 6	0-8-24	May 29	—0.60°	—	—0.57°
Nov. 6	0-8-24	Sept. 4	—0.62°	—	—0.61°
Nov. 6	Nitrate soda	Sept. 4	—0.66°	—	—0.63°
Nov. 24	None	—	—0.64°	—	—0.63°
Nov. 24	0-8-24	May 29	—0.68°	—	—0.67°
Dec. 17	None	—	—0.52°	—0.53°	—0.53°
Dec. 17	0-8-24	May 29	—0.71°	—0.70°	—0.69°
Dec. 17	0-8-24	Sept. 4	—0.67°	—0.68°	—0.66°
Dec. 17	Nitrate soda	Sept. 4	—0.68°	—0.67°	—0.67°

The soluble material in a small number of undried samples was determined by the freezing point method. Immediately upon digging, the roots were washed and ground after removing the external moisture. The determinations were made without addition of water. The freezing point depression of the Hardigan roots averaged —1.56° C and of the Arizona Common roots —1.50° C, when the roots were dug December 17. The results showed little difference in the concentration of soluble material in the roots of hardy and non-hardy alfalfas when measured by the freezing point method. This method cannot be used, therefore, to measure the winter hardiness of strains of alfalfa.

DISCUSSION

The relative winter hardiness of the various strains of alfalfa has been quite successfully determined by means of field tests. In order to insure a high degree of accuracy, the field tests must extend over a long period of time. A simple laboratory test for predicting winter hardiness would aid the agronomist in determining the relative winter hardiness of the different strains of alfalfa and also assist in explaining the phenomenon of winter hardiness. In this paper are presented data from comparative studies of roots of hardy and non-hardy strains of alfalfa including determination, by electrical conductivity, of soluble material liberated through submission to low temperatures; chemical composition; moisture equivalent, swelling, and heat of wetting of finely ground root material; amount and rate of loss of moisture; and respiration. These are factors which it was

thought might in part determine or explain the phenomenon of winter hardiness.

The electrical conductivity method was found useful in measuring the relative degree of hardening which had taken place in the alfalfa roots at the time the tests were conducted. No differences in hardening between hardy and non-hardy alfalfa were found on October 16, but marked differences were found on November 23, and at later dates. The varietal differences agreed with the results of previously conducted field tests. Hardening was found to develop most rapidly in the upper portion of the tap roots, while it was delayed in the lower portion and in the small lateral and hair roots. A heavy application of an 0-8-24 fertilizer on September 4 caused hardening to develop much more slowly during November and December.

Even though the electrical conductivity method was of value in determining the relative winter hardiness of different lots of alfalfa, it did not offer an explanation of the phenomenon of winter hardiness.

Three hypotheses may be suggested to account for the different degrees of winter hardiness found in the different strains of alfalfa, as follows:

1. Winter hardiness may be caused by a physico-chemical difference in the roots of hardy and non-hardy alfalfas, due to the condition of the material (whether colloidal, in solution, etc.) and composition (whether present as sugar, starch, and protein), and the structure of the tissue present. Factors such as heat of wetting, swelling, moisture equivalent, freezing point depression, chemical analysis, and the amount and rate of loss of moisture afford good indices of physico-chemical differences. These indices showed that there were no physico-chemical differences present in the roots of hardy and non-hardy alfalfas, therefore, affording no support for this hypothesis.

2. Winter hardiness may be caused by bio-chemical or functional differences brought about by the secretion of substances such as enzymes and hormones, and these differences reflected in the energy release in the cell protoplasm. The rate of respiration was used as and index of energy release and was found to be the same for both hardy and non-hardy alfalfas. The work of Dexter (8) and Tysdal (19) support these results. The acceptance of this hypothesis is not justified.

3. Winter hardiness is an hereditary factor transmitted from generation to generation. This hypothesis has not been worked out in detail by the geneticists and plant breeders. However, the behavior of succeeding generations of Hardigan, Grimm, Utah Common, Arizona Common, etc., in transmitting different degrees of winter hardiness affords sufficient evidence to warrant the acceptance of this hypothesis.

CONCLUSIONS

A search was made to find factors that could be used in the laboratory to predict the relative winter hardiness of alfalfas.

The results showed that the relative degree of injury of alfalfa roots by low temperature was indicated by electrical conductivity

and in this manner the relative winter hardiness of different lots of alfalfas was determined.

No direct relationship was found to exist between winter hardiness and heat of wetting, swelling, moisture equivalent, freezing point, chemical composition, respiration, and amount and rate of loss of moisture in roots of hardy and non-hardy alfalfas.

Heredity is the most plausible explanation of the phenomenon of winter hardiness.

For the time being it is necessary to adhere to field tests aided by electrical conductivity tests for determining the relative winter hardiness of different lots of alfalfas.

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SEED PRODUCTION OF SPACE-ISOLATED VS. BAGGED MOTHER BEETS AND A DISCUSSION OF SOME FACTORS INFLUENCING THE LATTER[1]

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THE most commonly used method of controlling pollination of sugar beets under Michigan conditions has been by space isolation as described by Down and Lavis (6).[3] The labor cost required to isolate a mother beet in a city garden naturally restricts the number of mother beets that can be used in any one season. The few hundred beets usually isolated in any one year are only a fraction of the number of selfings made by any corn breeder. This difference is still further enhanced by the factor of self-sterility found in many mother beets and by unavoidable losses of individual plants through one cause or another.

Various methods have been used by plant breeders for controlling pollination of beets. Space isolation has proved very satisfactory when care was taken to destroy nearby seed plants of Swiss chard and red garden beets (6, 2). Of the bagging material used, light-weight parchment and light-weight Kraft grocery bags have been the most satisfactory (15, 1, 6, 7, 2, 11, 16, 4). The bags of the heavier weight paper and also of glassine and cellophane seldom have seed set in them (16, 10, 4). Some workers have found that cages made of finely woven cloth have been very satisfactory in some cases (17, 2), but in others a great amount of crossing took place (14, 6).

Lack of success of seed production under bags has been attributed to various causes such as type of isolator (15, 11, 4); high temperature (17, 6, 2); high relative humidity (2); no insects to carry pollen (3, 13); protandrous nature of the beet (13); and inheritance of self-sterility (9, 2, 8).

The factors influencing the set of seed on isolated mother beets appear to be complex and much more intensive study is necessary to determine the effect of each factor and the interaction of the several factors. Seed production studies on mother beets, isolated under paper bags, were begun in 1930 in two widely separated localities and extended to a third locality in 1932. The data obtained in these experiments are for 4 years at East Lansing, 4 years at Burt Lake, and 2 years at Traverse City.

METHODS AND MATERIALS USED

The method of isolation of mother beets by bags and by space was the same as that described by Down and Lavis (6). A number of red garden beets were

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[3]Figures in parenthesis refer to "Literature Cited," p. 705.

distributed systematically over the area in the bagging experiment to determine whether or not foreign pollen entered the bags. Crosses of red garden beets on sugar beets are easily detected as the red color of the red garden beet is dominant in the F_1 generation.

The mother beets used for bagging were selected from commercial and inbred lots. All types of bagging material were placed on each mother beet wherever possible. This reduces greatly the possibility of the differences obtained between types of bagging material being due to differences in the self-sterility of the individual mother beets Fifteen kinds of bags were used in these experiments, a description of which is given in Table 1.

TABLE 1.—*Description of bags used in experiments.*

Reference No	Material	Size of bag
1	40 lb grease-proof white parchment	2 x 4 x 11 in.
2 S	30 lb. white parchment	4 x 11 in.
2 M	30 lb white parchment	6 x 18 in.
2 L	30 lb white parchment	8½ x 23 in.
3	40 lb white parchment	2 x 4 x 11 in.
4	40 lb white parchment	6 x 18 in.
6	40 lb. Mosinee (brown grocery)	10 lb.
7	50 lb Union Hemp (extra heavy brown grocery)	12 lb
8	30 lb Union Tiger (Kraft grocery)	10 lb
11 S	Hard finish filter paper	4 x 11 in.
11 M	Hard finish filter paper	6 x 18 in.
11 L	Hard finish filter paper	8½ x 23 in.
18	40 lb Tuff Buff (Kraft grocery)	5 lb.
19	Cloth bag covered with paraffin emulsion	6 x 12 in.
20	Pyralin (water proof and transparent tube)	3 in. dia. x 16½ in.
21 S	No 450 cellophane	4 x 11 in.
21 M	No 450 cellophane	6 x 18 in.
22	No. 600 cellophane	6 x 18 in.
23 S	Glassine (weight not known)	4 x 11 in.
23 M	Glassine (weight not known)	6 x 18 in.
23 L	Glassine (weight not known)	8½ x 23 in.
24	Paper flour bags, 50 lb white parchment	¼ bbl
25	Paper flour bags, heavy white paper, inner surface blue	¼ bbl
26	Paper flour bags, heavy brown hemp	¼ bbl.

Some of the bags were found to be practically useless as they had very few seeds set in them. The results with Nos. 1, 3, 4, 20, 21, 22, 23, 24, 25, and 26 are omitted for that reason.

PRESENTATION OF DATA

SPACE ISOLATION VS. PAPER BAGS

The most satisfactory bag tested for 3 or more years to control the pollination of mother sugar beets was one made from 30 lb. white vegetable parchment 8½ inches wide and 23 inches long, designated as No. 2. A comparison of the results obtained from this bag and from space isolation in city gardens is shown in Tables 2 and 3.

The data in Tables 2 and 3 indicate that control of pollination by space isolation of beets had two advantages over control of pollination by the use of paper bags. These were (a) the average production of seed per beet was 25 51 grams for those space isolated as

TABLE 2.—*Date obtained from mother beets space isolated in city gardens.*

	1930	1931	1932	1933	Average
No. beets isolated	518	571	639	307	508.75
No. beets with seed stalks	431	427	315	199	343.00
Percentage beets with seed stalks that set seed	87.94	88.29	90.79	76.38	87.03
Percentage with seed of all beets isolated	73.17	66.02	44.76	49.51	58.68
Yield of seed per plant that set seed, grams	32.40	25.21	18.31	26.13	25.51

TABLE 3.—*Data obtained from mother beets bagged with one No. 2 (30 lb. white vegetable parchment) bag each.*

	1930	1931	1932	1933	Average
No. beet plants bagged	37	51	97	87	57.87
No. beet plants with undamaged bags	25	25	87	45	44.75
Percentage beet plants with undamaged bags that set seed	40.00	44.00	36.78	40.00	39.01
Percentage all bagged beet plants with seed set	27.02	21.57	32.99	20.69	26.10
No. seeds per plant of all bagged beets with seed set*	32.40	76.55	41.44	74.72	54.04

*70 seeds weigh about 1 gram.

compared to less than a gram for those bagged with paper bags; and (b) 87.03% of the space-isolated beets with seed stalks set seed as compared to only 39.01% of beet plants with undamaged bags which had seed set in them.

Considering all beets, isolated and bagged, the percentage of space-isolated beets bearing seed was more than double that for the bagged beets.

The following advantages accruing from bagging beets to control pollination were found: (a) Less time required for planting. A larger number of beets can, therefore, be planted early in the spring without serious interference from heavy rains. Early planting is essential for seed production since late-planted beets usually do not develop seed stalks. (b) Practically no crossed seed was found under the bags. Beets grown in 1933 from the bagged seed showed that 6 bags out of 166 contained a trace of hybrid seed. No indication of cross fertilization was found in the bagged seed planted in 1934. (c) Accidental destruction of mother beets, as often happens with beets isolated in city gardens, is almost entirely eliminated.

The comparative disadvantage in the small amount of seed produced on beets under bags can be decreased by placing more than one bag on a beet. Data on this subject are not available for the No. 2 bags, but they are available for the No. 8 bags (Table 4). These data show that the percentage of beets with seed set and the number of seeds per plant was increased. These increases, however, were not in proportion to the number of sacks used, and the yield of seed per plant remained much below that of the space-isolated mother beets.

TABLE 4.—*Comparative results from mother beets bagged with one to five No. 8 (10 lb. Union Tiger grocery) bags in 1933.*

	One bag per plant	Five bags per plant
No. beet plants bagged	64	213
No. beet plants with one or more undamaged bags	42	182
Percentage beet plants with undamaged bags with seed set	33.33	51.63
Percentage all bagged beet plants with seed set	21.88	44.60
No. seeds per plant*	45.86	57.15

*70 seeds weigh about 1 gram.

FACTORS INFLUENCING SET OF SEED WITHIN BAGS

Size of bag.—The size of bag also influenced the set of seed. The data shown in Table 5 indicate that the large bags were more easily damaged by wind than the small bags, but the former had a higher percentage of undamaged bags with seed produced in them and had more seeds per bag than the latter.

TABLE 5.—*The effect of size of bag upon the set of seed.**

Bags used	Total No. bags	Undamaged bags %	No. bags with seed	Undamaged bags with seed %	Per cent all bags with seed	Average no. seeds per bag with seed	Average no. seeds per bag for all bags used
2 S	513	81.84	154	36.84	30.02	27.58	8.28
2 M	446	70.40	134	42.68	30.04	38.88	11.68
2 L	456	61.40	133	47.50	29.17	55.89	16.30

*The data are a summary of 4 years' (1930–33) work at East Lansing and Burt Lake and 2 years (1932 and 1933) at Traverse City.

Shading and shaking.—A group of mother beets were divided into two lots. One lot was shaded by fastening burlap sacks to stakes on the east, south, and west sides of the beets in such a manner that the sun did not shine on the bags. The bags were shaded from the time they were put on until harvest time. The second lot was not shaded. The bags on one-half of the beets in each lot were shaken daily for about 3 weeks after they were put on. The data obtained are presented in Table 6.

TABLE 6.—*The effect of shading and shaking the bags upon the set of seed at East Lansing in 1931.*

Bags used	Shaken		No treatment		Shaded and shaken		Shaded	
	No. undamaged bags	Seed set %	No. undamaged bags	Seed set %	No. undamaged bags	Seed set %	No. undamaged bags	Seed set %
2 S	59	38.98	43	37.21	17	23.53	25	12.00
2 M	43	53.49	51	29.41	17	11.76	23	13.04
2 L	36	38.89	25	44.00	12	25.00	19	5.26
Average		43.48		35.29		19.57		10.45

Shaking the bags daily during the flowering period was beneficial to the set of seed. Shading the bags was detrimental to seed production. Shaking the shaded bags daily increased the percentage of shaded bags that set seed, but the percentage was much below that of the groups not shaded.

Type of isolator.—The data obtained and shown in Tables 7, 8, and 9 varied greatly for the different kinds of material used and for the different locations. The materials, however, had definite relative values for the control of pollination and these values at the three stations were usually in the following order: Nos. 18, 2, 8, 6, and 7.

TABLE 7.—*Data obtained from various kinds and sizes of bags on mother beets for control of pollination at East Lansing, Mich., 1930–33.*

Bags used	No. years tested	Total No. bags	Undamaged bags %	No. bags with seed	Undamaged bags with seed %	Per cent all bags with seed	Average no. seeds per bag with seed	Average no. seeds per bag for all bags used
2 S*	4	311	86.45	83	30.86	26.69	32.54	8.68
2 M*	4	257	82.06	71	33.65	27.63	40.62	11.68
2 L*	4	272	66.91	71	39.01	29.78	54.04	14.11
6	2	169	70.41	21	17.65	12.43	33.10	4.11
7	3	193	84.97	26	15.85	13.47	29.19	3.93
8	3	189	66.67	35	27.78	18.52	39.00	7.22
11 S	1	6	83.33	2	40.00	33.33	3.00	1.00
11 M	1	7	71.42	1	20.00	14.29	9.00	1.29
11 L	1	8	75.00	3	50.00	37.50	10.00	3.75
18	1	73	86.30	26	41.27	35.62	47.35	16.86
19	1	69	100.00	19	27.54	27.54	27.32	7.52

*Undamaged bags only were counted in 1930. Corrections were made on a basis of their performance in other years.

TABLE 8.—*Data obtained from various kinds and sizes of bags on mother beets for control of pollination at Traverse City, Mich., 1932 and 1933.*

Bags used	No. years tested	Total No. bags	Undamaged bags %	No. bags with seed	Undamaged bags with seed %	Per cent all bags with seed	Average no. seeds per bag with seed	Average no. seeds per bag for all bags used
2 S	2	84	77.38	33	50.77	39.29	38.79	15.24
2 M	2	78	56.41	30	68.13	68.18	54.27	20.87
2 L	2	69	53.62	28	75.68	40.58	87.11	35.35
6	2	63	61.90	23	58.97	36.51	47.78	17.44
7	2	59	81.36	29	60.42	49.15	35.97	17.68
8	2	62	59.67	30	81.08	48.39	49.60	24.00
18	1	49	95.92	34	72.34	69.39	52.79	36.63

This placing is very close to the placing of Nos. 2, 18, 8, 6, and 7, as judged by the amount of light that appeared to pass through these bags when held before a lamp, and suggests a very close relationship between set of seed and the moisture content in the bags and the amount of light that passes into the bags.

TABLE 9.—*Data obtained from various kinds and sizes of bags on mother beets for control of pollination at Burt Lake, Mich., 1930–33.*

Bags used	No. years tested	Total no. bags	Undamaged bags %	No. bags with seed	Undamaged bags with seed %	Per cent all bags with seed	Average no. seeds per bag with seed	Average no. seeds per bag for all bags used
2 S	4	118	71.19	38	45.24	32.20	7.00	2.25
2 M	4	111	53.15	33	55.93	29.73	21.18	6.30
2 L	4	115	53.04	34	55.74	29.57	34.03	10.06
6	2	64	92.19	19	32.20	29.69	21.95	6.52
7	3	105	95.24	30	30.00	28.57	10.60	1.03
8	3	89	83.15	28	37.84	31.46	27.07	8.52
18	1	25	100.00	11	44.00	44.00	13.45	5.92

Climate.—It was found that a much higher percentage of the undamaged bags at Burt Lake and Traverse City had seed set in them than at East Lansing (Table 10), except in the case of the planting at Burt Lake in 1933. This exception was due, at least in part, to

TABLE 10.—*A comparison of the percentage of undamaged bags that had seed set in them.*

Bags used	1930	1931	1932	1933
	East Lansing			
2 S	26.19	37.21	21.92	42.03
2 M	39.22	29.41	23.68	38.21
2 L	40.00	44.00	36.78	40.00
Average	31.39	35.29	27.97	43.53
	Burt Lake			
2 S	57.14	46.15	48.78	34.78
2 M	71.43	100.00	56.67	26.67
2 L	75.00	45.00	65.38	45.45
Average	66.67	55.00	55.67	34.69*
	Traverse City			
2 S	—	—	50.00	51.36
2 M	—	—	55.56	71.43
2 L	—	—	57.14	80.00
Average	—	—	52.27	66.67

*Most of the mother beets were infected with disease before planting.

the fact that more of the mother beets showed signs of disease infection before planting at Burt Lake than did the mother beets at the other stations. The higher percentage set of seed could not be explained on soil fertility differences alone as the mother beets at East Lansing were grown on soil heavily fertilized while the beets at Traverse City were grown on sandy unfertilized soil. The soil at Burt Lake was more sandy than at East Lansing, but it had been a grass sod and plowed before planting the beets. The climatic differences, such as temperature and rainfall, apparently were great enough to influence the set of seed of sugar beets.

SUMMARY

A much larger amount of seed can be obtained from mother beets when isolated by space than when isolated by bagging. This advantage is offset by (a) the longer time required for space isolating; (b) danger of bad weather preventing isolation until warm weather begins, which decreases the number of mother beets sending up seed stalks; (c) danger of crossing with Swiss chard or garden beets; and (d) danger of destruction by careless individuals. The disadvantage of small seed production under bags is offset to some extent by (a) small chance of cross pollination, and (b) no destruction of mother beets by careless individuals.

Seed production under bags per mother beet can be increased by (a) placing several bags on each mother beet; (b) using thin bags; (c) using large bags; (d) shaking bags daily during flowering period; (e) not shading the bags; and (f) possibly by growing the mother beets in a cool section of the state.

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EFFECT OF TILLERS ON THE DEVELOPMENT OF GRAIN SORGHUMS[1]

A. T. BARTEL, J. H. MARTIN, AND R. S. HAWKINS[2]

IN most grain sorghum fields the plants are spaced sufficiently wide to allow the development of tillers. The highest yields of grain in freely-tillering varieties of milo and feterita usually have been obtained with plant spacings that produced considerable tillering (4, 5, 6, 8).[3] The tillers often bear a considerable portion of the total grain yield, although under normal conditions the heads on the main stalks are larger than those on the tiller stalks. This investigation was undertaken to determine the effect of tillers and their removal upon the development of the main stalk and upon the total grain yield of Dwarf hegari.

REVIEW OF LITERATURE

Tillers have frequently been regarded as detrimental in grain sorghums and the selection of seed heads from plants without tillers has been recommended (1, 7). More recent and complete investigations (5, 6), however, have suggested the undesirability and futility of these early recommendations.

Hastings (3) recommended a rate of planting sufficiently heavy to prevent tillering in milo at San Antonio, Tex., finding that attacks of the sorghum midge could be reduced by early and uniform flowering. Plants with a lesser number of tillers resulted in a larger number of erect heads, more uniformity, and higher grain yields under these special conditions.

Tillers, or suckers as they are often called, have been a problem in many crop plants, especially corn. As early as 1909, Williams (10) removed the suckers in corn to determine if they were injurious to the yields. Reductions in the weight of grain per stalk, percentage grain to cob, and yield of stover were obtained by removing the suckers from the plants. Dungan (2) defoliated the main stalks of corn at the early milk stage, removing the suckers from some plants and allowing them to remain on others. Significant increases in weights were obtained from the plants having suckers over those from which the suckers had been removed. Nourishment for the main stalks was received from the suckers when they were left on the plants.

The physiological relations between the tillers and the main stalk of wheat have been worked out by Smith (9). He observed but slight translocation between different tillers of a plant after flowering. His results indicate that considerable photosynthesis can take place on the surface of the culms when the leaves have been removed. Any water taken up by the roots is distributed evenly to all of the tillers of a plant.

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[3]Reference by numbers in parenthesis is to "Literature Cited," p. 714.

METHODS

The experiments reported in this paper were carried on under irrigation during the summers of 1931, 1932, and 1933 at the University Farm, Tucson, Ariz. The variety Dwarf hegari was used in all the tests because it tillers readily and is also the principal grain sorghum grown in this region. The seed was planted on normal planting dates and the plants thinned to a distance of approximately 15 inches soon after they were up. The plants received normal irrigation, except that in 1932 and 1933 an additional series was grown in which no irrigation water was applied after early jointing.

The tillers were removed from the plants at the following stages: (a) As soon as they formed, (b) when the leaves of the main stalk had unrolled, and (c) at heading of the main stalk. The leaves of the main stalk were removed at (a) unrolling, (b) heading, and (c) at the soft dough stage of the kernels. The unrolling of the leaves of the main stalk occurs 2 to 3 weeks before flowering. Removing the leaves of the main stalk earlier than 3 weeks before flowering resulted in barren stalks where the tillers were also removed. The term "heading" refers to the time when the head on the main stalk flowers. In cases where the tillers were removed as they formed, there was a continual removal of tillers until no more developed. In tests where the leaves of the main stalk were removed at unrolling, the new growth was cut off on alternate days until leaf growth ceased with the appearance of the head.

The removal of leaves and tillers at heading was conducted on an individual plant basis; that is, each plant was taken as a unit, and it was not until the main head had flowered that its leaves and tillers were removed. In the other determinations, all the plants were treated as a group. For example, when the tillers and leaves were removed at unrolling, all the plants were so treated regardless of their number of leaves or stage of unrolling.

All the weights recorded are in grams and on an air-dry basis. No stalk weights were obtained in 1932.

In the normal irrigated plats a total of 90 plants were used for each treatment in 1931, 50 plants in 1932, and 75 plants in 1933. Fifty plants were used for each determination in the plats receiving a single irrigation in 1932 and 60 plants in 1933.

RESULTS OBTAINED

The results obtained from the removal at different stages of the tillers and leaves of the main stalk of the plants grown under normal irrigation are presented in Table 1 and in Figs. 1 and 2.

When the main stalks were defoliated at unrolling, i. e., 2 or 3 weeks before flowering, an increase in the weights and number of grains per head occurred as the length of time the tillers were allowed to remain on the plants increased. The average weight of seed per head was 3.6 grams on stalks from which the tillers were removed as they formed, but when the tillers were allowed to remain on the plants the average weight was 16.5 grams.

The heads on the stalks defoliated at the early unrolling stage were very small (Figs. 2 and 3).

In no case did all the main stalks head when their leaves were removed at unrolling and the weights shown are averages for the heads that were harvested. During the 3 years the experiments were conducted an average of 23.4% of the main stalks headed when the

TABLE 1.—*Effect of defoliation and tiller removal upon weights of stover and grain of Dwarf hegari.*

Stage of tiller removal	Weight in grams of										Threshing percentage of heads, 3-year average
	Stover per stalk		Grain per head				100 kernels				
	1931	1933	1931	1932	1933	Av.	1931	1932	1933	Av.	
Main Stalk Defoliated When Upper Leaves Were Unrolled											
When formed	19.9	16.3	2.1	5.5	3.1	3.6	0.72	0.90	1.42	1.01	60.0
Unrolling	26.8	—	4.0	6.7	0.0	3.6	0.77	1.10	—	0.94	75.4
Heading	21.8	23.4	4.5	10.0	10.3	8.3	0.94	1.30	1.52	1.25	69.8
None: Main stalk	21.6	39.1	6.8	21.7	20.9	16.5	1.62	1.82	2.70	2.05	83.8
None: Average tiller	56.4	80.4	37.8	35.4	59.2	44.1	2.74	2.15	2.89	2.59	84.7
None: All tillers per plant	—	—	85.5	72.5	137.2	98.4	—	—	—	—	—
Main Stalk Defoliated at Heading Stage											
When formed	49.1	81.4	11.7	23.9	32.9	22.8	0.61	0.81	1.29	0.90	59.5
Unrolling	54.3	58.9	12.9	24.5	22.7	20.0	0.65	1.14	1.06	0.95	59.5
Heading	48.9	48.9	12.6	19.0	19.6	17.1	0.65	0.92	0.86	0.81	61.0
None: Main stalk	54.5	74.1	35.8	37.0	60.9	44.6	1.63	1.65	2.48	1.92	79.5
None: Average tiller	48.9	68.8	26.9	26.0	48.5	33.8	2.51	2.09	2.66	2.42	81.8
None: All tillers per plant	—	—	53.4	52.8	125.8	77.3	—	—	—	—	—
Main Stalk Defoliated at Milk Stage											
When formed	80.3	121.6	66.3	82.0	94.6	81.0	2.11	2.46	3.11	2.56	81.7
Unrolling	82.3	98.6	69.3	64.5	79.2	71.0	2.34	2.61	2.91	2.62	81.3
Heading	74.1	99.2	69.1	62.2	74.9	68.7	2.36	2.41	2.96	2.58	82.7
None: Main stalk	63.6	77.4	57.6	48.2	68.8	58.2	2.24	2.17	2.74	2.38	82.2
None: Average tiller	62.2	69.3	33.7	25.4	50.8	36.6	2.65	2.33	2.81	2.60	81.7
None: All tillers per plant	—	—	56.8	51.9	90.7	66.5	—	—	—	—	—
Main Stalk Not Defoliated											
When formed	121.2	194.5	89.2	77.1	100.8	89.0	2.80	2.73	3.45	2.99	85.5
Unrolling	141.0	158.0	83.0	83.9	95.2	87.4	3.16	2.81	3.60	3.19	83.1
Heading	145.2	174.7	73.9	57.3	76.0	69.1	3.00	2.54	3.21	2.92	83.9
None: Main stalk	84.7	86.4	66.7	47.6	70.8	61.7	2.61	2.09	3.02	2.57	83.9
None: Average tiller	54.0	75.2	30.2	26.5	48.8	35.2	2.58	2.15	2.75	2.49	82.8
None: All tillers per plant	—	—	61.2	56.6	91.4	69.7	—	—	—	—	—

tillers were removed as they formed, 14.1% when the tillers were removed at unrolling, 73.1% when the tillers were removed at heading, and 60.0% of the main stalks headed when the tillers were allowed to remain on the plants. No heads were produced in 1933 when the leaves of the main stalk and the tillers were removed at unrolling. In the other determinations practically 100% of the main stalks headed.

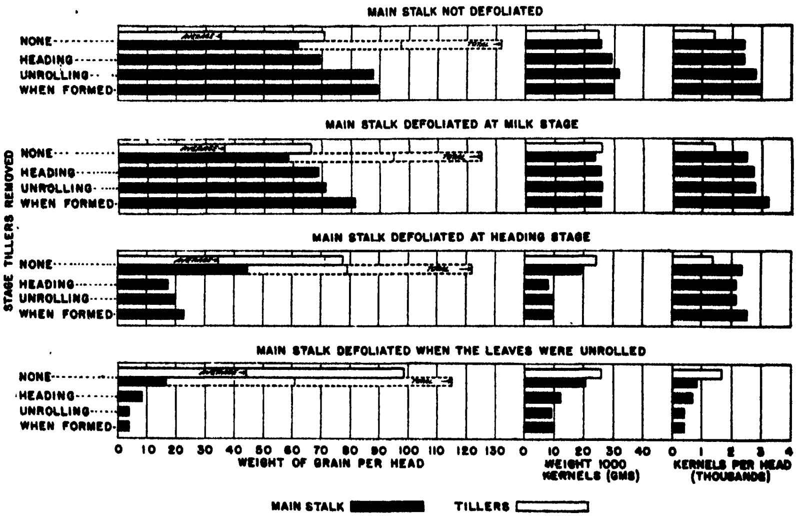


FIG. 1.—Effect of defoliation and tiller removal on weight of grain per head, weight of 1,000 kernels, and number of kernels per head in Dwarf hegari.

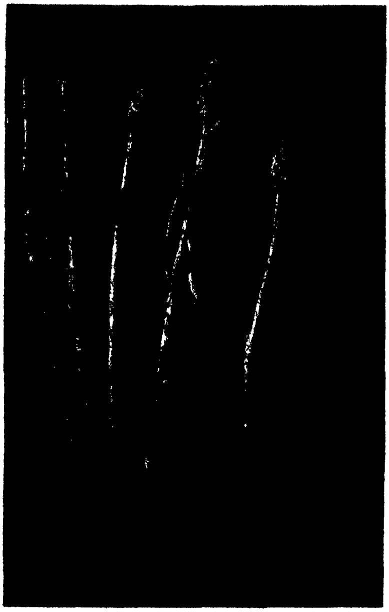
It is evident that tillers were beneficial to the development of the main stalk when the leaves of the main stalk were removed as early as 2 or 3 weeks previous to flowering. The tillers were much heavier than the main stalks after defoliation at this stage.

When the leaves of the main stalk were removed at the heading stage, the sooner the tillers were removed, the higher was the average stalk weight and average weight of grain per head. Tillers that were removed were thus eventually detrimental to the development of the main stalk under these conditions. However, when the tillers were allowed to remain on the plants, a decided increase in the main stalks was obtained in stalk weight, weight of grain per head, and weight of 100 kernels. The number of kernels per head (Fig. 1) was nearly the same, so the increased size of kernel was due to food material supplied by the tillers.

The average weights of seed per head on plants defoliated at heading were from two to six times those on the corresponding plants defoliated at unrolling. With the greatly increased number of kernels per head on the plants defoliated in the heading stage, and with no leaves or tillers for further synthesis, the reduced weight of kernel observed was to be expected.

When the leaves of the main stalks were removed at the soft dough stage or allowed to remain, a gradual decrease in the weight of the main stalk resulted from delaying tiller removal. The differences were due chiefly to the development of more kernels when the tillers were removed early. When the tillers were allowed to remain on the plants, the main stalks produced less grain than did those of the plants from which the tillers were removed. The detrimental effect of tillers upon the main stalks was very noticeable both in the stover and grain weights. The tillers, however, produced much more than enough to offset the smaller main stalks.

The number of kernels per head (Fig. 1) was slightly larger and the weight of kernels considerably greater on the stalks undefoliated, or defoliated in the milk stage, than on those defoliated at the heading stage. The threshing percentage (percentage of grain in the heads) is determined to a considerable extent by the size of kernel (Table 1) and consequent-



A B C

FIG. 2.—Plants of Dwarf hegari showing effect of defoliation and tiller-removal on plant development. A, tillers not removed, main stalk defoliated at flowering; B, tillers removed and main stalk defoliated at flowering; C. tillers removed and main stalk defoliated 3 weeks before flowering.

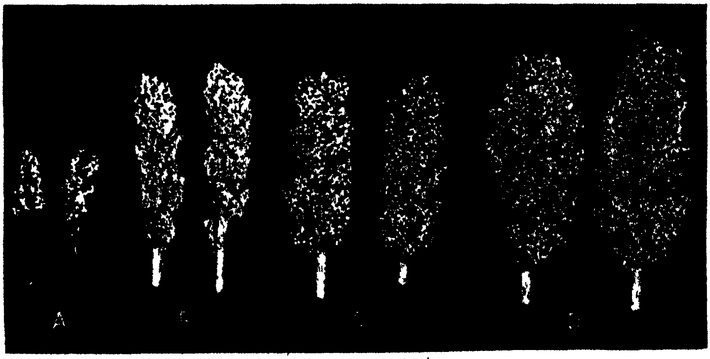


FIG. 3.—Heads of Dwarf hegari from main stalks, defoliated 3 weeks before flowering (A, B, C) and from plants not defoliated (D). A, tillers removed when formed; B, tillers removed when main stalk headed; C and D, tillers not removed.

ly is low in the main heads of the plants from which the leaves and tillers were removed in the heading stage or earlier.

In 1933 an additional experiment was carried on in which the tillers were defoliated a few days after flowering while the leaves of the main stalk were allowed to remain on some plants but in others were removed a few days after flowering. These results are shown in Table 2.

TABLE 2.—*Effect of defoliation of the main stalks upon the development of defoliated tillers on the same plants.*

Stalk	Weight in grams of			Threshing percentage of heads
	Stover	Grain per head	100 kernels	
	Main Stalks Defoliated			
Main	39.4	15.4	1.23	70.6
Tiller	25.6	10.7	1.03	69.9
	Main Stalks Not Defoliated			
Main	69.7	62.6	2.63	85.3
Tiller	34.6	36.1	1.88	84.7

When the leaves of the main stalk were removed, the weights of stalk and grain were greater on the main stalks than on the defoliated tiller stalks. The main stalk was usually slightly larger and earlier than the tiller stalk.

There was a decided increase in the weights of the tillers when the leaves of the main stalk were allowed to remain. The weight of grain per head increased from 10.7 grams to 36.1 grams in the tiller stalk and the weight of 100 kernels was increased from 1.03 grams to 1.88 grams due to nourishment they received from the main stalks.

DEFOLIATION AND TILLER REMOVAL UNDER DROUGHT CONDITIONS

In 1932 and 1933 some of the plants received only one irrigation each year, applied in the early jointing stage. The results in general were so nearly the same as where normal irrigation was applied that the data obtained will not be presented.

The most noticeable difference between the normally-irrigated and the drought-affected plants was the reduced stalk weight in the latter, especially when the leaves and tillers were removed after the heading stage. This was undoubtedly due to the slightly shorter stalks of the drought-affected plants.

DISCUSSION

When the leaves of the main stalk were removed early, the tillers were definitely beneficial and aided in the nourishment of the main stalk. Also, when the leaves of the tiller stalks were removed and the leaves of the main stalk allowed to remain, the main stalk nourished the tiller stalks and greatly increased their weights. These results lead one to conclude that the plant juices containing organic nutrients are free to move from the tiller to the main stalk, or from

the main stalk to the tiller, depending upon where the nutritional deficiency is found. The vascular connection between the main stalks and the tillers is shown in Fig. 4.

When the leaves of the main stalk were removed late in the development of the plants, as in the soft dough stage, the tillers were detrimental to the development of the main stalk. This was also true when the main stalks were not defoliated.

FIG. 4.—Vascular connection between main stalk and tillers of Dwarf hegari.

Although the tiller removal ("suckering") of Dwarf hegari increased the yields of undefoliated main stalks, the increase was less than the grain and stover produced by the tillers themselves. It appears that the main stalk and tillers of a plant ordinarily compete for nutrients, but it is important to remember that tillers usually develop and produce heads only when the moisture and fertility supply is sufficient for both main stalk and tiller growth. Each tiller develops a root system of its own.

SUMMARY

Tillers and leaves of the main stalks of Dwarf hegari, a grain sorghum, were removed at various stages of plant development.

Tillers increased the development of the main stalks of Dwarf hegari when the leaves of the latter were removed previous to heading, and the longer the tillers were left on the plant, the greater were the weights of the main stalk.

When the leaves of the main stalk were removed at the soft dough stage of the kernels or when the leaves of the main stalk were allowed to remain, the longer the tillers were left on the plants, the lower were the weights of the main stalk. Tillers in such cases seem detrimental to the development of the main stalk but produce more than enough grain and stover to offset the decreased growth of the main stalk.

There is evidence that plant juices are free to move from the main stalk to the tillers or from the tillers to the main stalk, depending upon where the nutritional deficiency occurs. A vascular connection exists between the main stalk and tiller stalk.

The effects of the tillers on the main stalks of plants subjected to drought were about the same as on the plants receiving ordinary irrigation.

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CORRELATING YIELD WITH PHENOLOGICAL AVERAGES TO INCREASE EFFICIENCY IN WHEAT BREEDING[1]

B. G. Moussouros and D. C. Papadopoulos[2]

A great deal of work has been done in Greece during the last decade to improve the acre yield of wheat. An important part of this work has to do with testing and propagating imported varieties and selections from native varieties. Due to the great diversity in climate and soil types which characterize Greece, as well as to the great variation in weather conditions from year to year, this task involved a good deal of time and energy and every possible effort should be put forth in carrying on an efficient wheat breeding program with the limited means and personnel available.

Such efforts should be directed not only toward defining ecological areas and properly locating the experimental fields, but also in establishing general principles and specific criteria which would aid in selecting strains from local stock and varieties created abroad without waiting for yields. Furthermore, certain of these principles and criteria should be employed to determine how long one should continue testing promising varieties, or at what stage of the testing process the undesirable ones should be discarded.

A review of the literature on this subject indicates that formerly agriculturalists who dealt with wheat problems in this country thought of the introduction from abroad of earlier varieties as one of the most effective means for improving the wheat yield on the theory that in eastern Greece, where the annual rainfall ranges from 15 to 20 inches and dry weather prevails late in the spring when the wheat crop matures, these varieties would be able to escape the spring drought and hot winds to which were attributed the low yields obtained in this country. Later it was found that the black rust was also responsible for reducing the yields.

As early as 1892, Chassiotis (2),[3] working in Thessalie, the largest wheat-producing district of Greece, analyzed the factors affecting wheat yield and pointed out the need for the introduction of wheat varieties from abroad which "would be more productive, of a better quality, early maturing, and resistant to drought and to lodging."

Yenadios (12) in discussing the advantages of Rieti wheat, especially its earliness and high gluten content, recommends its testing with the hope that by escaping the hot wind which blows usually in May, it might give good results.

Zalokostas (11), testing the Australian wheat Cedar in Yiannina, and Evelpidis (3) the wheat Indian in Patras, report that these wheats present special interest for Greece on account of their earliness.

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[2]Assistant agronomists. The writers wish to thank Prof. Papandreou for making available the material on which this study is based. They are also indebted to Prof. H. H. Love for having read the manuscript and given valuable suggestions.

[3]Figures in parenthesis refer to "Literature Cited," p. 723.

Papandreou (6), reporting results on testing an early Vilmorin wheat resistant to lodging, points out that this wheat is earlier than those of the Greek soft wheats but three to four days later than the hard red wheats grown in eastern Greece. Later, in reporting results on testing certain wheats created by Strampelli and on a very early black oat of Vilmorin, he (7) stresses their value for their earliness and the high yields obtained in the experimental plats of the Superior School of Agriculture in Athens.

Papadakis (8), in discussing problems of developing early varieties and kinds resistant to drought, points out the need for testing early Australian and California wheats. In later publications he (9, 10) analyzes the results of wide experimentation with these early varieties to ascertain their value for northeastern Greece and recommends them for propagation among farmers.

The above-stated opinions have been confirmed lately by the significant results obtained with certain spring wheats introduced from abroad and grown over a large area in this country. On this basis, therefore, it must be considered as a guiding principle that early varieties should be the center of attention of any successful wheat breeding program in eastern Greece.

The next step is to analyze the factor of "earliness" and determine more specifically for southeastern Greece, where the experimental plats of the Superior School of Agriculture are located, (a) what phenological averages should be taken as an index of the yielding capacity of varieties under these conditions; and (b) what are the time limits within which varieties should head and mature in order to avoid the early spring frosts which are so frequent in this part of Greece, and on the other hand, escape the dry weather at the critical period of growth and complete their maturity under the most favorable conditions.

To this end yields have been correlated for a group of varieties over a 4-year period with the number of days from planting to heading, from planting to maturity, and from heading to maturity.

MATERIAL USED

The data on which this study is based include 99 wheat varieties and strains taken out of a large number of varieties and selections which are being tested each year in the experimental plats of the Superior School of Agriculture in Athens. The wheats included in this group were grown every year during a 4-year period, in plats of 4 square meters on the same experimental field, were planted on the same date or within two days, and had a normal growth during the year.

Yield determinations were based on single plats as well as on replicated ones. In 1930–31, 36% of the plats were replicated from two to four times; in 1931–32, 43%; in 1932–33, 36%; and in 1933–34, 14%. Variation in single plats was measured by the variety Gremenia which was used as a check every year. In 1930–31 the standard deviation in percentage of the mean was 33%; in 1931–32, 20%; in 1932–33, 36%; and in 1933–34, 31%. (See Table 2.)

The number of days from planting to heading and from planting to maturity were also considered for each variety. On this basis, the number of days which elapsed between heading and maturity was calculated.

Due to the fact that the varieties were taken at random as far as the degree of earliness was concerned, and since the relative degree of earliness of each case inserted in the correlation tables has a direct influence on each coefficient of correlation, the analysis of the material presented in Table 1 regarding the earliness of each variety, has special interest. Table 1 refers to the time of heading of each variety under the climatic conditions prevailing in Athens.

TABLE 1.—*The distribution of 99 wheat varieties on the basis of time of heading, Athens, Greece.*

Classification	Time of heading	No. of varieties
Very early	Previous to April 18	1
Early	Between April 18 and 28	12
Average	Between April 28 and May 11	53
Late	After May 11	33
Total		99

While the distribution of the 99 wheats given in Table 1 was made on the basis of quite a few years of experience and for a more or less normal year as regards the distribution of rainfall and early spring temperatures, the information given in Table 2 indicates that there is a considerable variation in the time of heading from one year to another for each variety. This variation extends to 16 days for the 4-year period, while the sowing was done within a period of less than a month. This point is illustrated by the curves in Fig. 1, which at the same time show the basis on which the wheats were classified in Table 1. Furthermore, these curves indicate that the variability within the group for each one of the 4 years is very limited, the coefficients of variability ranging from 4.96 to 6.10% for heading and from 2.73 to 3.51% for maturity. It will be observed also from the shape of the four curves that the late-maturing varieties constitute a distinctly separate group which comes to heading in a short period of time, and therefore, renders difficult the distinction between late and very late varieties. Undoubtedly this is due to the dry weather which prevails during May and which hastens the heading of certain very late varieties.

DISCUSSION

In general, the coefficients of correlation given in Table 3 are, with the exception of one instance, very significant as measured by Fisher's method. The negative correlations observed between yield and number of days to heading and number of days to maturing indicate that "earliness" of varieties is of prime importance in obtaining high yields, and further confirm a fact which in the beginning of this paper was considered as an established principle. However, an analysis of the data of the first two columns of Table 3 shows

TABLE 2.—*The lowest, the mean, and the highest value in time of heading, maturity, number of days between heading and maturity, and yield for the four variables, using the standard variety Gremenia as check.*

Year and date of planting	Values	No. of days from sowing to heading	No. of days from sowing to maturity	No. of days between heading and maturity	Yield
1930–31......	Earliest	128 (April 9) Ballila, 290 gr.	168 (May 19) Ballila, 290 gr.	16, Australia, 380 gr.	S. Boyta (April 18 & May 8), 100 gr.
Dec. 2–3, 1930	Mean of all varieties	154 (May 2)	185 (June 5)	30.5	408 gr.
	Latest	171 (May 22) Vilm. 29, 150 gr.	198 (June 16) Vilm. 29, 150 gr.	46 Mentana, 575 gr.	B.X.I.P. (April 30 and May 31), 935 gr.
	Gremenia	143 (April 24)	182 (June 2)	39	Mean of 6 replications, 365±48 gr.
1931–32	Earliest	122 (April 23) Ballila, 2,550 gr.	159 (May 30) Florence, 1,150 gr.	17, Virgilio, 0.870 gr.	Leventis (May 12 and June 10), 270 gr.
Dec. 23, 1931	Mean of all varieties	143.5 (May 14)	170 (June 10)	28	912 gr.
	Latest	160 (May 30) Hyb. Alliees, 900 gr.	181 (June 22) Vilm. 23, 1,170 gr.	41, Ballila, 2,550 gr.	Ballila (April 23 and June 3). 2,550 gr.
	Gremenia	138 (May 8)	169 (June 10)	33	Mean of 25 replications, 1,196±49 gr.
1932–33	Earliest	133 (April 11) Ballila, 1,420 gr.	174 (May 22) Mentana, 1,070 gr.	21, Mazolino, 0.250 gr.	Asprostaro (May 13 & June 10), 120 gr.
Nov. 29, 1932	Mean of all varieties	159.5 (May 7)	191 (June 8)	31.5	510 gr.
	Latest	175 (May 23) Vilm. 27, 570 gr.	207 (June 24) Vilm. 27, 570 gr.	42, Arnaouti, 210 gr.	Ballila (April 12 and May 21), 1,420 gr.
	Gremenia	154 (May 2)	185 (June 2)	31	Mean of 12 replications, 608±64 gr.
1933–34	Earliest	109 (April 12) Ballila 1,920 gr.	148 (May 21) Florence 1,230 gr.	14, Kamboura, 155 gr.	Triminia (May 16 and June 1), 75 gr.
Dec. 24, 1933	Mean of all varieties	130.5 (May 3)	159 (June 1)	29	834 gr.
	Latest	144 (May 17) R. P. Barbu, 130 gr.	173 (June 15) Australia, 1,200 gr.	45, B. P. X. I., 1,910 gr.	Duretranger (May 1 & June 5) 2,230 gr.
	Gremenia	122 (April 25)	155 (May 28)	33	Mean of 13 replications, 1,268±110 gr.

*Standard errors.

that we should distinguish between earliness in heading and earliness in maturity, the former being of much greater importance as an index of the yielding capacity of the varieties than the latter which should be regarded rather as a correlary condition of heading, much depending on weather conditions.

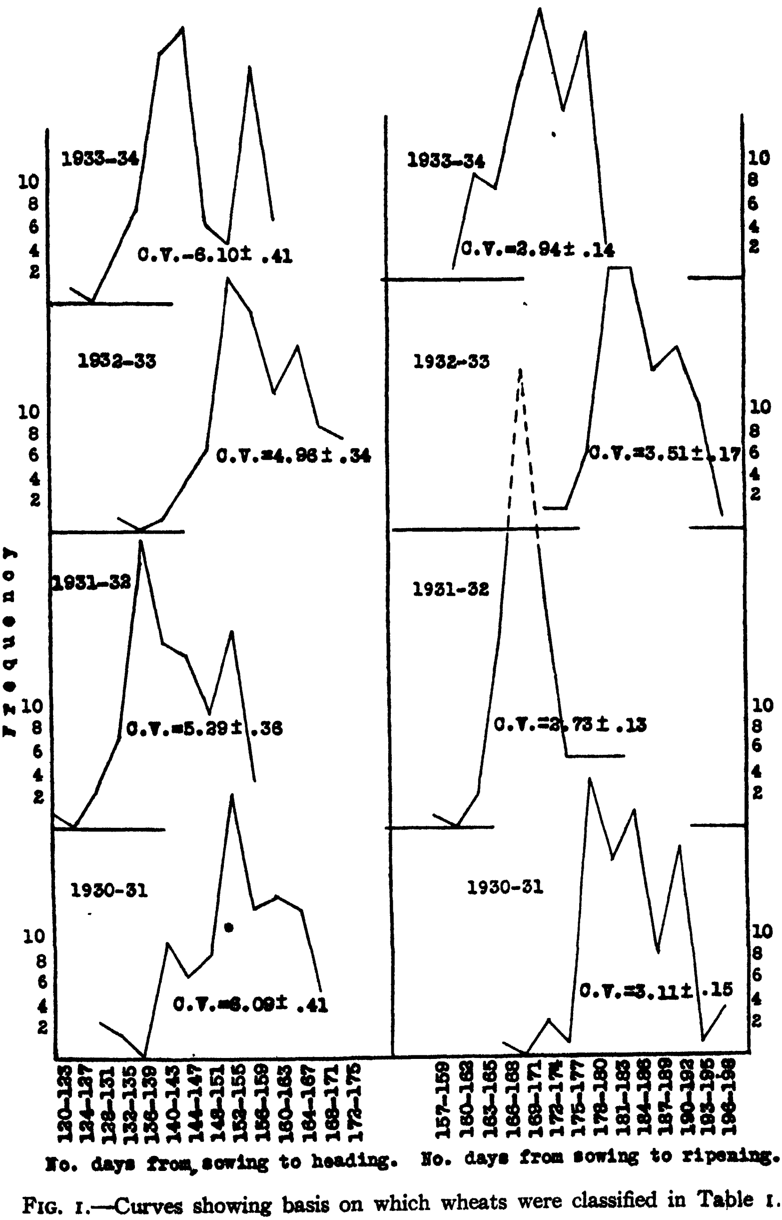

FIG. 1.—Curves showing basis on which wheats were classified in Table 1.

TABLE 3.—*The degree of correlation between yield and number of days from planting to heading and to maturity, and number of days between heading and maturity for a 4-year period.*

Crop years	Correlation coefficient between yield and		
	No. of days to heading	No. of days to maturity	No. of days between heading and maturity
1930–31........	—.471	—.441	+.401
1931–32........	—.726	—.250	+.529
1932–33........	—.371	—.218	+.990
1933–34........	—.357	—.030	+.486

Note: n = 100 and P = 5%. Coefficients above .1946 are significant. (See Fisher's table giving values of correlation coefficients for different levels of significance.)

In 1930–31 a good degree of negative correlation was observed between yield and number of days to maturity due to a combination of exceptional weather conditions—low temperature in March ranging from —1° to —5.6° C, with rainy weather in April and May—which favored the development of black rust to such an extent that all varieties were more or less severely attacked by the disease. Obviously the earlier varieties were attacked by rust in a latter stage of maturity and this explains why the early maturing varieties gave higher yields in 1930–31.

In contrast to the correlation coefficients between yield and number of days to maturity, which fluctuate greatly in the 4-year period, coefficients between yield and number of days to heading are more consistent. The high degree of negative correlation observed in 1931–32 should be regarded as one of the highest coefficients ever attained with the given group of varieties due to the fact that after a rainy March (77.5 mm), the subsequent period up to June was practically dry so that, while there was enough moisture in the soil at the critical period of the earlier heading varieties, the late varieties were severely handicapped by dry weather. On the contrary, in 1933–34, a low degree of correlation was observed between yield and number of days to heading on account of the dry weather which prevailed in March and April (5.4 mm) at the critical period for early varieties, the yields of which were materially reduced, while on the other hand, the rainy, cool weather in May favored the average and some of the late varieties which gave exceptionally good yields. Both these years should be considered as exceptional in so far as the distribution of rainfall is concerned.

According to weather data supplied by Aeginitis (1) for Athens, there have been 5 years out of 46 with a spring as dry as that of 1931–32, and 4 years with a dry April (below 10 mm) and May above normal as in 1933–34. It seems, therefore, that the lowest and highest coefficients observed in the 4-year period between yield and number of days to heading should be regarded as marking practically the limits in the range of these coefficients. Furthermore, the fact that in 17 years out of 46 rainfall in April and May was below normal and that in 9 of these years there was practically no rainfall,

with only 11 years with rain above normal at the same period, suggests that in the long run there are greater probabilities of having years with a dry spring, as in 1931–32, and therefore with a high coefficient, than years with a dry April and rainy May as in 1933–34, which resulted in a low coefficient. The distribution of rainfall at Athens during the 4 years of these studies is presented in Table 4.

The significance of earliness in heading is further stressed by the good and constant correlation obtained between yield and number of days from heading to maturity (Table 3) which means that the more the maturity period is extended, the higher the yield obtained. This is obviously another way of saying that the earlier heading varieties will give higher yields, for so long as the maturity period is checked by dry weather it follows that in order to have the longest maturity period heading should start as early as possible. Therefore, the correlation coefficients in columns 2 and 4 of Table 3 indicate to a certain extent the same thing in two different ways.

TABLE 4.—*Distribution of rainfall at Athens with the respective number of rainy days in the 4-year period 1930–34, and during a normal year.**

Crop year	Total rainfall, normal year, mm†	Rainfall, July–Feb., mm	Rainfall by months, mm				
			March	April	May	June	Total for 4 months
1930–31	544.3	403.9	33.2 (8)‡	52.6	34.7	19.9	140.4
1931–32	368.3	275.7	77.5 (13)	12.1 (3)	0.0 (0)	3.4 (2)	92.9
1932–33	286.5	193.1	12.6 (6)	26.4 (10)	30.5 (4)	23.9 (5)	93.4
1933–34	410.2	300.1	60.3 (16)	5.4 (6)	31.6 (12)	12.8 (5)	110.1
Normal year	393.3	290.8	34.3 (10.6)	20.7 (8.5)	19.6 (7.5)	17.2 (4.6)	91.8

*From observations made by the weather office of the Superior School of Agriculture, Athens.
†Given by Aeginitis (1).
‡Figures in parenthesis number of rainy days.

On the basis of the above discussion it seems quite evident that attention should be directed toward obtaining early heading strains and varieties which at the same time will develop a drought resistance complex in order to extend their maturity period as long as possible.

Information given by Aeginitis (1) suggests that varieties can head as early as the middle of March without danger of injury by early spring frosts. According to these data, in 40 years out of 46 minimums of temperature in March ranged between 0° and 10° C and only in 6 years were temperatures below 0 observed. However, field observations indicate that, as a rule, every year the tops of the leaves of early varieties are injured by frosts in March, and in some years, as in 1931 when the frost was so constant, the spikes of early varieties which are beginning to form at that time are injured also. Observations made by Kyriazopoulos (4) in Athens on the minimum

temperature on the top of grass throw some light on this problem. He found that the minimum temperatures on the top of grass were, as a rule, lower than the minimums on the surface of the ground, both grassy and barren, and always lower than the respective air minimums. The difference between air minimums and that on the top of the grass ranged from —0.3° to —7.1° C for the 11 days of 1931 during which air minimums below 0° were observed. On March 20, 28, and 29 air minimums were —1.8°, 0.0°, —2.2°, respectively, while the minimums on the top of the grass for the same dates were —6.8°, —0.3°, and —5.6° C. Furthermore, during 1931, temperatures below 0° were observed 50 times on the top of grass. He concludes that these exceptionally low temperatures on the top of the grass cannot be detected through the usual air temperature and soil observations.

These observations, although covering a period of 1 year, conclusively indicate that air and soil temperature minimums cannot be used in deciding up to what time varieties can head without being damaged by frosts, and that data like that given by Kyriazopoulos for a long period of time are needed in order to answer the above question.

The data on hand, as well as field observations to date, suggest that it is not wise to try to obtain varieties heading earlier than Ballila, which heads during the first 10 days of April in Athens, unless these varieties would develop cold resistant qualities at the same time. Thus, it seems that in addition to the need for obtaining varieties which would extend their ripening period as long as possible by developing a drought resistance complex, we must look for varieties which at the same time will be able to resist early spring frosts. Although it has been found that in general resistance to both freezing and drought is due to the same structural and physiological qualities, the experimental work of Martin (5), who found that spring wheats differ relatively little in cold resistance when actively growing at the time the spikes begin to form, indicates that there are not so many possibilities in this field.

SUMMARY

Yields have been correlated for a group of 99 wheat varieties over a 4-year period with the number of days from sowing to heading, from sowing to ripening, and with the number of days which elapsed from heading to ripening. The wheats were sown every year on the same date in plats of 4 square meters on the same experimental field. Actual yields for each case were taken together with their corresponding number of days from sowing to heading and ripening. On this basis the number of days between heading and ripening was also calculated.

In general, a good correlation was found to exist between yield and the three variables confirming the prevailing idea among Greek agriculturalists that "earliness" is of prime importance in obtaining high wheat yields in eastern Greece.

In analyzing the data a sufficiently constant association was found to exist between yield and number of days to heading to indicate

that this phenological average might be taken as an index of the yielding capacity of the variety. The significance of this index was further stressed by the high and consistent positive coefficients of correlation between yield and number of days elapsing from heading to ripening, inasmuch as usually the maturity period is checked by dry weather and in order to have the longest maturity period, as this coefficient indicates, heading should start as early as possible.

Furthermore, with the available data and with field observations to date, it is not wise to try to obtain varieties heading earlier than Ballila, which heads the first 10 days of April in Athens, unless the varieties develop besides a drought-resistant complex which would enable them to extend their ripening period as long as possible and which would at the same time enable them to resist early spring frosts.

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EFFICIENCY OF AMMONIATED SUPERPHOSPHATES FOR COTTON[1]

J. T. WILLIAMSON[2]

THE process of using superphosphate as an absorbent for ammonia, although known for many years, was not practiced extensively in the fertilizer industry until about 1928. Its use began commercially when the production of synthetic nitrogen compounds made cheap ammonia available for fertilizers.

The simple process of ammoniation is of considerable economic importance for the several reasons enumerated by Jacob and Ross.[3] One of the most important reasons given was that it afforded a way of using anhydrous ammonia, one of the cheapest forms of nitrogen available to the fertilizer industry. A serious problem of importance to all interested in the production and use of mixed fertilizers was the fact that the addition of ammonia to superphosphate resulted in the formation of less soluble phosphates. Keenan's[4] work showed that superphosphate, carrying 89.4% of the phosphoric acid as mono-calcium phosphate and 10.6% as di-calcium phosphate, on ammoniation to 2% ammonia contained 12.3% of the phosphoric acid as mono-calcium phosphate, 36.4% as di-calcium phosphate, and 51.3% in the form of mono-ammonium phosphate. On increasing the ammonia content to 4%, the superphosphate was found to contain 14.7% di-calcium phosphate, 43.5% tri-calcium phosphate, and 41.8% mono-ammonium phosphate. Ammoniation to 6% ammonia changed the phosphate to 79% tri-calcium and 21% mono-ammonium phosphate.

In order to determine the influence of the less soluble, and supposedly less available phosphates, on the yield of cotton, a considerable number of field experiments were conducted. In these experiments, a study was made of the efficiency of superphosphate, ammoniated superphosphates carrying approximately 2 and 4% nitrogen, and precipitated tri-calcium phosphate. This paper reports averages of the results obtained in Alabama during 1931 to 1934, inclusive.

PROCEDURE

All of the experiments reported were conducted cooperatively with farmers. In this paper the term "experiment" refers to the studies made on one series of plats during a single year. The method of replication employed was to locate a

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[2]Associate Agronomist. The writer wishes to express his appreciation to F. E. Bertram, J. W. Richardson, and J. R. Taylor, Jr., for assistance with the field work in connection with the experiments herein reported.

[3]JACOB, K. D., and ROSS, W. H. Chemical nature and solubility of ammoniated superphosphates and other phosphates. Jour. Amer. Soc. Agron., 23 : 771. 1931.

[4]KEENAN, FRANK G. Reactions occurring during the ammoniation of superphosphates. Jour. Ind. and Eng. Chem., 22 : 1378. 1930.

single series of plats on one farm and repeat the experiment on the same soil series in other communities, or perhaps, in the other counties.

Experiments were conducted on the following soil series: Clarkesville and Dickson soils of the Highland Rim; Decatur and Dewey soils of the Limestone Valleys; Hartsells soils of the Appalachian Plateau; Cecil soils of the Piedmont Plateau; and Norfolk, Kalmia, Ruston, Greenville, Orangeburg, and Cahaba soils of the Coastal Plain.

For convenience in tabulating the data, similar soils have been grouped and each soil group has been named for the soil series on which the majority of the experiments within the group was conducted. The Greenville soil group of the Coastal Plain includes the results of experiments on Greenville, Orangeburg, and Cahaba soils and the Norfolk group of this region includes the results of experiments on Norfolk, Ruston, and Kalmia soils.

RESULTS

A study of the data in Tables 1 and 2 shows that these experiments were conducted on soils which responded well to the applications of phosphoric acid. Only the Greenville soil group failed to produce as much as 200 pounds increase of seed cotton per acre from the use of 60 pounds of phosphoric acid. On the Highland Rim and the Appalachian Plateau increases of 308 and 298 pounds of seed cotton per acre, respectively, resulted from the superphosphate application. In the average of all experiments, superphosphate produced an increase of 241 pounds of seed cotton per acre.

The 2% ammoniated superphosphate produced an average increase of 242 pounds of seed cotton per acre, which is practically the same increase as that obtained from superphosphate. No significant differences in the results with 2% ammoniated superphosphate and the untreated superphosphate were obtained on any soil group unless the 20-pound difference in the increases on the Limestone Valley soils should be so considered.

Four per cent ammoniated superphosphate produced an average increase of 218 pounds of seed cotton per acre. If the increase due to superphosphate is assumed to be 100, the increase due to 4% ammoniated superphosphate is 90. Except on the Greenville soil group where the increase due to phosphoric acid was lowest, 4% ammoniated superphosphate was less effective than untreated superphosphate by amounts varying from 14 to 46 pounds of seed cotton per acre. The 4% ammoniated superphosphate was least effective the first year that these experiments were conducted (1931) and each year thereafter became increasingly effective as compared with superphosphate until 1934 when it gave an average increase practically equal to that of superphosphate. As most of these experiments were conducted on the same areas from year to year, the increase in the effectiveness of the ammoniated superphosphate was probably due to the cumulative effect of the phosphate.

Precipitated tri-calcium phosphate was on the average only 85% as effective as superphosphate. It was equally as effective as 4% ammoniated superphosphate on the Highland Rim, Limestone Valley, Appalachian Plateau, and Piedmont Plateau soils. However, it was

TABLE 1.—*Average yield of seed cotton, using different sources of phosphate on various soil regions of Alabama, 1931–1934, inclusive*

Plat No.	Fertilizer treatment*	Source of phosphate and kind of supplement	Pounds of seed cotton on: Highland Rim Clarksville soils, 29 expts.	Limestone Valley, Decatur soils 33 expts.	Appalachian Plateau, Hartsells soils, 28 expts.	Piedmont Plateau, Cecil soils, 27 expts.	Coastal Plain: Greenville soils, 19 expts.	Coastal Plain: Norfolk soils, 49 expts.	Average of all soils, 185 expts.
1	6–0–4	None	667	983	793	677	828	744	781
2	6–10–4	Superphosphate	948	1,201	1,081	947	926	986	1,021
3	6–10–4	Ammoniated superphos (2% N)†	943	1,221	1,074	953	932	980	1,022
4	6–10–4	Ammoniated superphos (4% N)‡	902	1,185	1,054	933	930	960	998
5	6–10–4	Precipitated tri-calcium phos.	903	1,178	1,063	944	877	925	986
6	6–0–4	None	627	1,000	772	709	827	757	782
7	6–10–4	Superphosphate and ground limestone§	1,015	1,252	1,164	1,043	914	1,016	1,074
8	6–10–4	Ammoniated superphos (4% N)‡ and ground limestone§	943	1,170	1,109	972	898	967	1,014
11	6–0–4	None	626	979	785	668	834	764	776
Average 6–0–4 plats			640	987	783	685	830	755	780

*600 lbs. per acre, nitrogen from ammonium sulfate sufficient to make 6% N, phosphoric acid from source indicated, potash from muriate of potash.
†Actual analysis was 1.53% N, 1931; 2.10% N, 1932; 2.06% N, 1933; 2.00% N, 1934. Average 1.92% N.
‡Actual analysis was 5.40% N, 1931; 4.65% N on Norfolk, Greenville, and Cecil groups and 3.64% N on Hartsells, Decatur, and Clarksville groups in 1932; 4.01% N, 1933; 4.00% N, 1934. Average 4.40% N.
§Marble dust, 200 lbs. per acre, in 1931; 200 lbs. dolomite per acre in 1932, 1933, and 1934.

TABLE 2.—*Average and relative increases of seed cotton on various soil regions from different sources of phosphate.*

Plat No.	Source of phosphate and kind of supplement*	Highland Rim, Clarkesville soils, 29 expts.	Limestone Valley, Decatur soils, 33 expts.	Appalachian Plateau, Hartsells soils, 28 expts.	Piedmont Plateau, Cecil soils, 27 expts.	Coastal Plain		Average all soils, 185 expts.
						Greenville soils, 19 expts.	Norfolk soils, 49 expts.	
		Increase in Pounds Seed Cotton per Acre						
2	Superphosphate	308	214	298	262	96	231	241
3	Ammoniated superphos. (2% N)†	303	234	291	268	102	225	242
4	Ammoniated superphos. (4% N)‡	262	198	271	248	100	205	218
5	Precipitated tri-calcium phos.	263	191	280	259	47	170	206
7	Superphosphate and ground limestone§	375	265	381	358	84	261	294
8	Ammoniated superphos. (4% N)‡ and ground limestone§	303	183	326	287	68	212	234
		Relative Increase						
2	Superphosphate	100	100	100	100	100	100	100
3	Ammoniated superphos. (2% N)†	98	109	98	102	106	97	100
4	Ammoniated superphos. (4% N)‡	85	93	91	95	104	89	90
5	Precipitated tri-calcium phos.	85	89	94	99	49	74	85
7	Superphosphate and ground limestone§	122	124	128	137	88	113	122
8	Ammoniated superphos. (4% N)‡ and ground limestone§	98	84	109	110	71	92	97

*Fertilizer 600 lbs. per acre of 6–10–4. Nitrogen from ammonium sulfate sufficient to make 6% N; phosphoric acid from source indicated; potash from muriate of potash.

†Actual analysis 1931, 1.53% N; 1932, 2.10% N; 1933, 2.06% N; 1934, 2.00% N. Average 1.92% N.

‡Actual analysis was 5.40% N, 1931; 4.65% N on Norfolk, Greenville, and Cecil groups and 3.64% N on Hartsells, Decatur, and Clarkesville groups in 1932; 4.01% N, 1933; 4.00% N, 1934. Average 4.40% N.

§Marble dust, 200 lbs. per acre, in 1931; 200 lbs. dolomite per acre in 1932, 1933, and 1934.

much less effective than the 4% ammoniated superphosphate on both of the soil groups of the Coastal Plain. Like the 4% ammoniated superphosphate, there was an apparent accumulative effect of this material from year to year, but the results were not so consistent as with the ammoniated phosphate.

Ground limestone applied at the rate of 200 pounds per acre with the superphosphate mixture gave an increase of 53 pounds of seed cotton per acre. However, when used at the same rate with the 4% ammoniated superphosphate mixture, the increase due to the ground limestone was only 16 pounds.

SUMMARY

The average results from 185 experiments with cotton on different soil groups and with various fertilizer treatments are reported and may be summarized as follows:

1. The increases in the yield due to phosphorus were greatest on the Highland Rim and the Appalachian Plateau soil groups and least on the Greenville soil group of the Coastal Plain.

2. The relative increases due to the different sources of phosphorus on all except the Greenville soil group were in accord with the relative increases obtained in the average of all experiments.

3. Using the increase due to superphosphate as a basis, the relative increases due to the different sources of phosphorus in the average of all experiments were as follows:

Superphosphate	100
Ammoniated superphosphate (2% N)	100
Ammoniated superphosphate (4% N)	90
Precipitated tri-calcium phosphate	85

4. Ground limestone used with the complete fertilizer containing superphosphate produced an average increase of 53 pounds of seed cotton per acre; but when used with the complete fertilizer containing 4% ammoniated superphosphate, the increase due to lime was only 16 pounds of seed cotton per acre.

NITRIFICATION OF AMMONIATED PEAT AND OTHER NITROGEN CARRIERS[1]

R. O. E. DAVIS, R. R. MILLER, AND WALTER SCHOLL[2]

CONSIDERABLE interest has been exhibited during the last few years in possibilities of preparing fertilizers from humic materials derived from peat, lignite, and coal. The use of such materials has been recommended for the effects produced on the physical condition of soils in improving their moisture relations and aeration and in producing conditions favorable to greater bacterial activity in the soil.

Lieske (7, 8, 9)[3] and Kissel (4, 5) have carried out extensive experiments tending to show the advantages of these materials. On the other hand, Lemmermann (6), while obtaining some favorable results in field trials from ammonium humate prepared from peat, believed the material could not be produced economically enough to warrant its commercial employment. Fuchs, Gargarin, and Kothny (2) made extensive water and pot cultures with humates prepared from brown coal and obtained some specially promising results with some preparations on certain plants, while the same preparations were not so effective with other plants. Their results on the whole were not conclusive. Crowther and Brenchley (1) have carried out parallel pot, field, and nitrification tests of humates prepared from coal which showed close correlation with each other. They concluded that the ammonia in ammonium humate is about as effective as ammonium sulfate and there was some indication that humic material alone supplied a small amount of available nitrogen.

Possibilities for fertilizer use were indicated by Scholl and Davis (12) in the preparation of a somewhat similar material by the treatment of peat with anhydrous ammonia, thereby obtaining a product with an enhanced amount of nitrogen. Investigation of the value of ammoniated peat as fertilizer material has led to experiments in the conversion of the contained nitrogen into nitrate in the soil. It is generally conceded that the rapid formation of nitrate indicates the presence of a form of nitrogen readily available for plants. Other forms of nitrogen than nitrate may be utilized, but the rate of nitrification in the soil furnishes to some degree a comparison of the readily available nitrogen in nitrogen compounds.

TESTS PERFORMED

Nitrification tests were made in several series of experiments, the first over a period of 2 months, the second for 23 weeks, and the remaining for periods of 10 to 13 weeks. The materials used included ammonium sulfate, cottonseed meal,

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[2]Senior Chemist, Assistant Scientific Aid, and Assistant Chemist, respectively. The authors wish to express their appreciation to F. E. Allison for helpful suggestions in arranging the tests, and for assistance rendered by J. R. Adams, J. C. Bryan and S. R. Hoover in carrying out some of the tests.

[3]Figures in parenthesis refer to "Literature Cited," p. 736.

blood, ammoniated peat prepared at 180°C and at 300°C, water-soluble portions and water-insoluble residues from ammoniated peat, raw peat representing the same nitrogen content as the other materials, raw peat of the same total weight as ammoniated peat, a sample with one-third nitrogen as sodium nitrate and two-thirds as the insoluble portion from the ammoniated peat prepared at 180°C, the soluble and insoluble portions from ammoniated dextrose, and similar materials. The ammoniated peat prepared at 180°C, used in the first series of experiments, contained 10.55% nitrogen; and that prepared at 300°C contained 18.50%. In the second series the nitrogen contents were 10.82% and 12.85% for the 180° and 300° treatments, respectively. The same raw peat employed for preparation of the ammoniated samples was used in the experiments on nitrification.

In preparing the water-soluble portion, 100 grams of ammoniated peat were washed successively on a large filter with 50-cc portions of water at 60°C until the leachings amounted to 2 liters. After cooling the solution was made to 2,000 cc and analyzed for the nitrogen content. This solution was used for the nitrification test on the water-soluble nitrogen.

It has been found as described previously (12) that ammoniated peat contains, on an average, about one-fourth of its total nitrogen as water soluble. Approximately 40% of the soluble nitrogen is present as urea, but the compounds making up the remainder of the soluble as well as the insoluble nitrogen are unknown. Investigations in this laboratory (11) have resulted in the separation from ammoniated products by extraction with various solvents of several groups of nitrogen compounds and determination of their amounts. Extracted residues from ammoniated peat and ammoniated dextrose were tested for nitrification.

Dextrose was ammoniated at 180° in a manner similar to peat, but the product obtained was about 65% liquid with an insoluble residue. The solid and liquid portions were separated and the residue washed with water as in the case of ammoniated peat. The residue and liquid portions were employed in nitrification tests. The nitrogen content of solid and liquid portions of ammoniated dextrose was 17.9% and 21.3%, respectively.

The ammonium sulfate, cottonseed meal, and dried blood were commercial materials of fertilizer grade. They were included to furnish known materials for purposes of comparison.

EXPERIMENTAL PROCEDURE

Nitrification tests were carried out in duplicate in the usual way by adding nitrogenous material containing 20 mg of nitrogen to 100 grams of soil. Soils from two locations were employed and contained 35 mg and 70 mg of nitrogen, respectively, per 100 grams of soil. The prepared samples were placed in a dark basement room of almost constant temperature of 30°C.

For the determination of nitrates the whole sample was transferred to a flask with 100 cc of water and shaken 2 hours. After filtering and washing, an aliquot of the solution was taken for determination of nitrate by the phenol disulfonic acid method (10). There are objections to this method under certain conditions where the color may be affected by chlorides or certain organic materials, but for our purposes the method was quite satisfactory.

RESULTS OF EXPERIMENTS

The results obtained in the various tests are summarized in Table 1, in which the conversions to nitrate are expressed as percentage of added nitrogen and of ammonium sulfate conversion as a maximum.

TABLE 1.—*Nitrification of ammoniated peat products and other materials.*

Material	Conversion to nitrates	
	From added N %	Relative to $(NH_4)_2SO_4$
$(NH_4)_2SO_4$	85	100
	90	100
	85	100
	80	100
Am peat, 180°	25	29
	31 1	34 4
Am peat, 300°	21	25
	13 4	14 8
Am peat, H_2O insol 180°	6	7
	17 3	19 1
Am peat, H_2insol 300°	7 5	8 3
Am peat, H_2O sol 180°	78	92
	82	91
Am peat, H_2O sol 300°	82	91
Raw peat	4	5
	0	0
	7	8
Am peat, H_2O insol 180°+$NaNO_3$	13 4	14 8
Soil alone	13 4*	—
	18	—
	19 1	—
	16	—
	14 2	—
Am peat, H_2O insol act 80†	10	12 5
Am peat, H_2O insol act 87	11	13 8
Am peat, H_2O insol act 50	12	15 0
Am lignin 180°	24	30
Am lignin H_2O—insol	8	10
Am starch, 180°	5	6 2
Am dextrose H_2O sol	40	44 3
Am dextrose, H_2O—insol	8 2	9 1
Am peat, extracted res	5 7	7 1
Am dextrose, extracted res	3 5	4 4
Cottonseed meal	49	58
	48 5	54
Dried blood	57	67
$MgNH_4PO_4$	93	109
Guanidine carbonate	6	7

*Original nitrogen in the soil converted to nitrate

†Act 80 87 50 refers to activity of insoluble nitrogen by neutral permanganate (A O A C) method

The first series of experiments was continued for 59 days. The conversions to nitrate nitrogen are shown in the curves of Figs. 1 and 2

The maximum conversion of ammonium sulfate was obtained in 17 days with a conversion of 85% of the added nitrogen. The nitrate formed from the water-soluble portion of ammoniated peat was still increasing on the 59th day with a conversion of 78% of the added nitrogen. Dried blood and cottonseed meal were next in order of nitrate formation, reaching fairly constant values in 17 days, with 57% and 49% conversion as the maximum, respectively. The two whole samples of ammoniated peat gave conversions to nitrate of

25% for the 180° product and 21% for the 300° product. The rates of nitrate formation were different, however, the 180° product reaching a maximum at 26 days and the 300° product at 59 days. The latter gave values slightly below the soil alone up to the 38th day followed by a rather rapid formation of nitrate. The samples of raw peat and of the insoluble residue from ammoniated peat showed small amounts of nitrates slowly formed; raw peat reaching a 4%

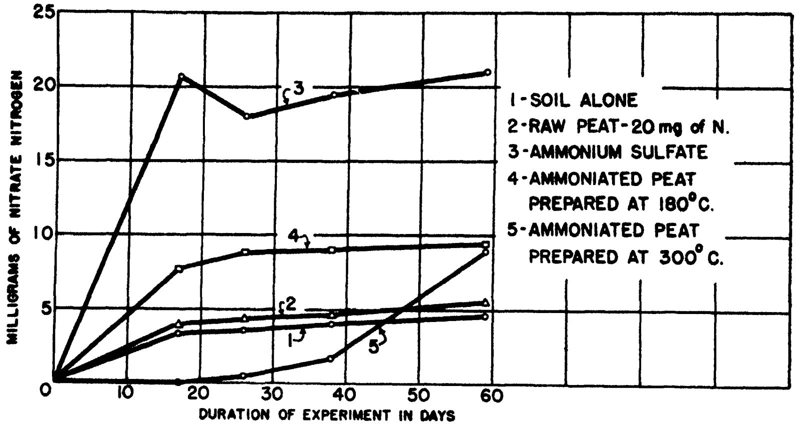

FIG. 1.—Series 1. Nitrification of nitrogenous materials.

conversion and the insoluble residue 6% on the 59th day. Compared to ammonium sulfate, the conversion to nitrate of cottonseed meal was practically half as great, and the whole ammoniated peats 25 and 29%.

The second series contained both soluble and insoluble portions of ammoniated peat, a mixture of sodium nitrate and leached residue, and products from ammoniated dextrose. This series was continued for 23 weeks, the summary of the results are shown in Figs. 3 and 4.

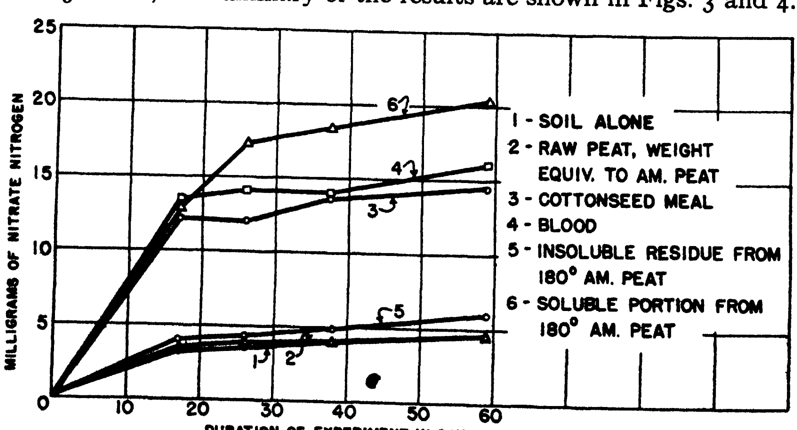

FIG. 2.—Series 1. Nitrification of nitrogenous compounds.

The nitrate maximum was reached in 6 weeks for 300° ammoniated peat at 13.4% conversion, the 300° ammoniated peat residue at 7.5%, the 180° ammoniated peat residue at 17.3%, and the 180° ammoniated peat residue with $NaNO_3$ at 13.4%. In 8 weeks maximum nitrate was shown for raw peat at 7.3% conversion, water-soluble portion of 300° ammoniated peat at 81.7%, 180° ammoniated peat at 31.1% and the soluble portion at 82.2%, and ammoniated dextrose

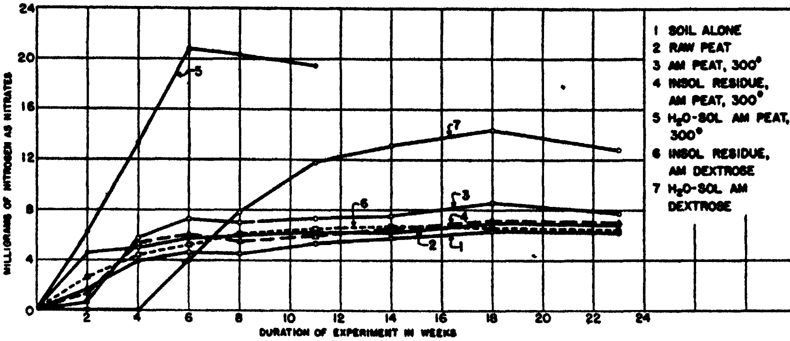

FIG. 3.—Series 2. Nitrification of nitrogenous materials.

residue at 8.2%. Ammonium sulfate reached maximum nitrification of 90.3% at 11 weeks, and cottonseed meal and water-soluble ammoniated dextrose at 18 weeks with 48.5% and 40.0% conversion, respectively. After the 8th week nitrate decreased in most cases and after the 18th week in all cases. The nitrate found at the end of 2 weeks was below the blank in the case of all fractions of the ammoniated peats prepared at 180° and 300° and of the soluble portion of ammoniated dextrose. With the exception of the dextrose fraction all had risen above the blank in nitrate content after 4 weeks; the dextrose fraction was considerably above the blank after 6 weeks. Included in the tests for comparison were magnesium ammonium sulfate and guanidine carbonate as different types of compounds. The magnesium ammonium phosphate prepared by W. H. Ross and K. C. Beeson of this Bureau, nitrified almost completely. The results from

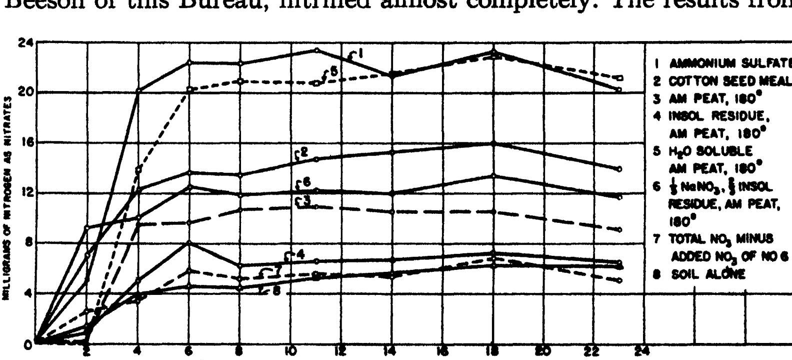

FIG. 4.—Series 2. Nitrification of nitrogenous materials.

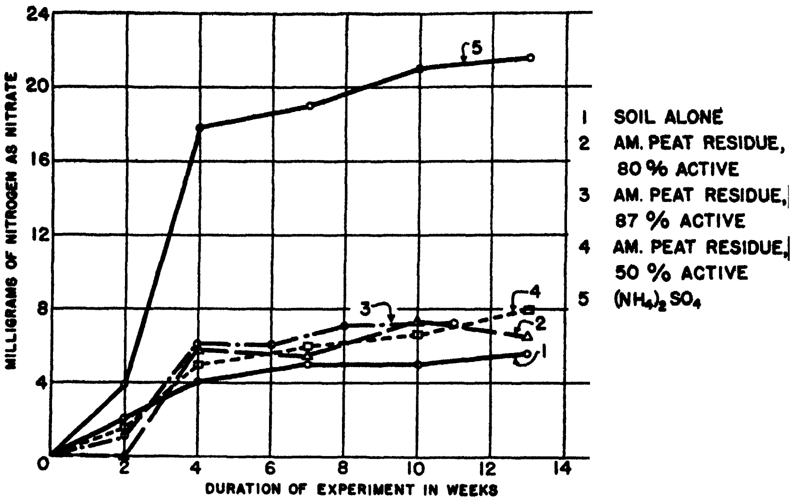

FIG. 5.—Series 3. Nitrification of ammoniated peat insoluble nitrogen of different activities.

guanidine carbonate were considerably lower than those obtained by Jacob, Allison, and Braham (3) for a similar period.

The series including ammoniated starch, ammoniated lignin and its insoluble residue, and the residues from three ammoniated peat samples showing activities by the neutral permanganate method of 50%, 80%, and 87% ran for 13 weeks. The results are summarized in the curves of Figs. 5 and 6 showing the rate and extent of nitrification.

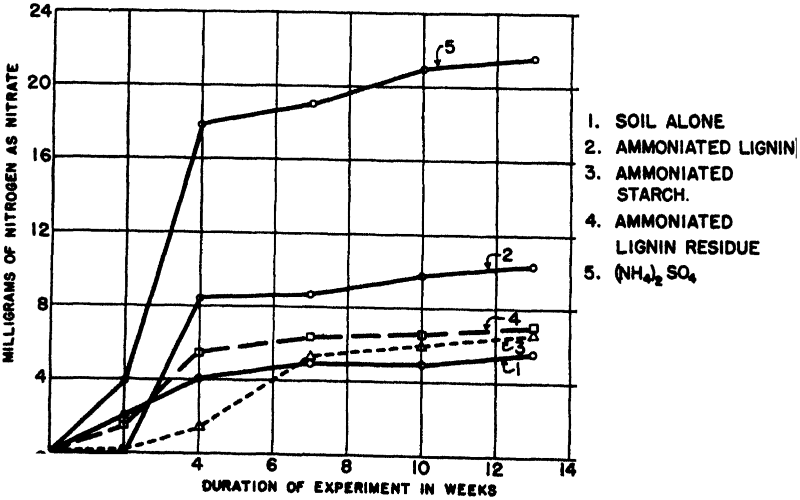

FIG. 6.—Series 3. Nitrification of ammoniated lignin and starch.

The conversion of ammonium sulfate in this series was somewhat lower than usual, reaching a maximum of only 80%. Ammoniated starch was lowest in conversion, 5.5%. Ammoniated lignin gave a 24% conversion and the insoluble lignin residue 8.0%. Ammoniated peat residues of 50%, 80%, and 87% activity gave 12%, 10%, and 11% conversion, respectively.

The fourth series contained only the blank and the residues from ammoniated peat and dextrose obtained from rather drastic extractions with various solvents. These were prepared by L. A. Pinck, L. B. Howard, and G. E. Hilbert of this laboratory (11). In the case of ammoniated peat, extractions were made successively with ether, water, alcohol, 2% and 1:1 hydrochloric acid, and the residue still contained 47% of the original nitrogen. Ammoniated dextrose received the same treatment, except extraction with 2% HCl, and the

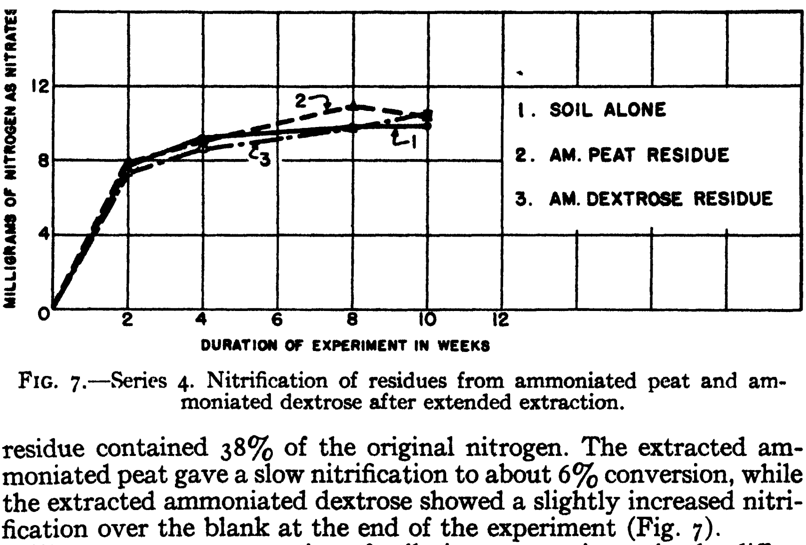

FIG. 7.—Series 4. Nitrification of residues from ammoniated peat and ammoniated dextrose after extended extraction.

residue contained 38% of the original nitrogen. The extracted ammoniated peat gave a slow nitrification to about 6% conversion, while the extracted ammoniated dextrose showed a slightly increased nitrification over the blank at the end of the experiment (Fig. 7).

The percentage conversion of soil nitrogen to nitrate in the different series of tests varied from 13 to 19. One soil employed in four tests contained 0.035% nitrogen and the other soil used in one test contained 0.07% nitrogen. The average maximum conversion of one soil amounted to 16.8% of the total original nitrogen and the maximum conversion in the other soil was 14.2%, or 16.3% for a general average.

SUMMARY

The nitrification of ammoniated products was used as an indicator of the ease of attack of the materials by bacterial action. Nitrification of ammoniated peat prepared at 180° and at 300° arrived at approximately the same maximum value in one series, of about 24% conversion to nitrates. In another series with different samples the 180° sample showed 31% conversion and the 300° sample gave only 13.4%. In both cases the nitrification of the 300° material was longer in starting and the rate was slower than with the 180° material, in-

dicating that the higher temperature had produced some effect that retarded the action of the bacteria.

Separation of the ammoniated peat into water-soluble and water-insoluble portions and subsequent nitrification tests showed that the water-soluble nitrogen compounds in both the 180° and 300° material were quite easily nitrified. The nitrification curve for this portion follows very closely that for ammonium sulfate, and the limited number of experiments indicates that the extent of nitrification is about the same as with ammonium sulfate. The soluble portion from ammoniated dextrose gave a maximum conversion of 40% after 18 weeks.

The leached residues from ammoniated peat left after extracting the water-soluble portion gave somewhat varying results, from 6 to 17% conversion to nitrate. Ammoniated lignin and its leached residue gave nitrification values corresponding closely to those of ammoniated peat. The whole ammoniated starch gave about the same value as raw peat and somewhat less than the water-leached residues from ammoniated peat. The water-leached residue from ammoniated dextrose gave 8.2% of the total nitrogen as nitrate after 8 weeks. Ammoniated peat residue and ammoniated dextrose residue from exhaustive extractions with several solvents were nitrified somewhat more in each case than raw peat. Ammoniated peat water-insoluble residue with sodium nitrate added gave a nitrification value of 13.4% after 6 weeks as contrasted with the 17% for a similar residue alone tested in the same series.

Three ammoniated peat water-insoluble residues, with active nitrogen of 50%, 80%, and 87% according to the neutral permanganate method, all gave low conversion to nitrate of approximately the same values, 12, 10, and 11%, respectively.

Magnesium ammonium phosphate nitrified at about the same rate as ammonium sulfate. Guanidine carbonate after 12 weeks had a conversion value of only 6%.

Soil nitrogen alone, as shown by the check runs, attained average conversion to nitrate of 16.3%, which is about equal to that of the leached residues from ammoniated peat and somewhat greater than the raw peat. This would indicate that the insoluble nitrogen of ammoniated peat becomes available as nitrate at about the rate of the nitrogen in the natural occurring soil organic matter.

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THE CLAY RATIO AS A CRITERION OF SUSCEPTIBILITY OF SOILS TO EROSION[1]

George John Bouyoucos[2]

CONSIDERABLE work is being done to discover principles governing and methods of predicting and distinguishing between erosive and non-erosive soils. The terms erosive and non-erosive as applied to soils are only relative for there is no absolutely non-erosive soil; under certain conditions, all soils will erode. But all factors being equal, save the soil factor, it is true that some soils erode much more readily than others. There is no doubt that there is a fundamental principle producing this difference and the problem is, of course, to discover this principle.

Middleton and his associates (1, 2, 3)[3] have done most excellent, extensive, and thorough study on the physical and chemical properties of soil which might influence soil erosion. As a result of those studies, Middleton has proposed the erosion ratio as the best single criterion of erosion. This erosion ratio is obtained by dividing the dispersion ratio by the ratio of colloid to moisture equivalent. The dispersion ratio is obtained by dividing the suspension percentage by the total percentage of silt and clay in the soil and multiplying by 100.

In studying the phenomena of slaking (4), the ultimate structure of soils (5), and the relative dispersibility of soils (6), and in making a mechanical analysis of the aggregate structure of soils (7), it was strongly impressed upon the writer that probably the major and fundamental principle governing and underlying the relative erosiveness of soils is the relation between the content of total sand plus silt and the total clay content. The researches cited above, together with those of other investigators (8), as well as practical experience, make common knowledge of the fact that the clay, together with the colloidal humus, tends to bind and cement soil particles into aggregates. It is on account of this binding and cementing effect that it is difficult to disperse soils, many of which require the application of enormous external energy to be dispersed (9).

With the above facts and conceptions in mind, the accuracy of the ratio of $\frac{\text{Sand} + \text{Silt}}{\text{Clay}}$ as an index of erosiveness of soils was put to a test on a large number of soils which are considered to be erosive and non-erosive. The preliminary results obtained seemed to show that the value of this ratio correlates with the erosiveness of soils. To put this method to a more critical and thorough test, it was decided to apply it on the various soils which Middleton and his associates of the U. S. Bureau of Chemistry and Soils have studied in connection with the problem of soil erosion by taking the reported

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[2]Research Professor.

[3]Figures in parenthesis refer to "Literature Cited," p. 741.

mechanical analysis of these soils and working out their $\frac{\text{Sand + Silt}}{\text{Clay}}$ ratio and then comparing this ratio with the erosion ratio which Middleton has proposed as the best single criterion of erosion.

In Table 1 are presented the data on the $\frac{\text{Sand + Silt}}{\text{Clay}}$ ratio which the writer has calculated from the published reports of the U. S. Bureau of Chemistry and Soils. This $\frac{\text{Sand + Silt}}{\text{Clay}}$ ratio will be designated hereafter for convenience as the clay ratio. For purpose of comparison, the erosion ratio which Middleton worked out on the same soils is also presented in Table 1.

TABLE 1.—*Comparison between the clay ratio and the erosion ratio in indicating the relative susceptibility of soils to erosion.*

Depth in inches	Clay per cent content	Clay ratio	Erosion ratio	Depth in inches	Clay per cent content	Clay ratio	Erosion ratio
Nipee Clay							
0–12	47.1	1.12	2.9	12–24	62.5	0.76	2.2
Aikin Silty Clay							
0–20	59.5	0.679	8.7	20–40	65.9	0.517	6.9
Davidson Clay Loam							
0–9	23.8	3.02	12.2	36–60	50.3	0.972	4.3
9–36	60.4	0.60	3.7	60–	29.6	2.36	7.7
Nacogdoches Fine Sandy Loam							
0–8	18.0	4.32	21.7	40–66	34.3	1.91	6.5
8–18	48.4	1.04	6.9	66–72	34.0	1.64	6.2
18–40	38.9	1.56	7.7				
Cecil Fine Sandy Loam							
0–6	25.3	2.86	25.8	6–24	58.6	0.701	6.0
Miles Clay Loam							
0–8	34.0	1.86	21.9	—	—	—	—
Houston Black Clay							
0–3	60.4	0.601	8.1	24–36	61.8	0.602	4.6
14–20	64.1	0.537	3.7	36–50	54.6	0.820	7.8
Colby Silty Clay Loam							
0–10	34.0	1.85	13.0	33–47	38.2	1.56	19.8
10–20	38.0	1.59	8.8	47–60	38.3	1.60	29.5
20–33	38.7	1.57	15.7	60–72	35.7	1.79	30.0
Marshall Silt Loam							
0–13	35.3	1.72	14.2	24–45	33.8	1.86	16.1
13–24	39.4	1.47	6.4	45–71	26.5	2.73	34.5
Palouse Silt Loam							
0–20	27.5	2.56	19.4	33–62	35.4	1.81	16.6
20–33	37.5	1.64	12.7	62–75	29.8	2.35	24.0
Iredel Loam							
0–5	16.4	4.55	24.2	10–20	63.1	0.56	15.0
5–10	16.4	5.05	15.7	20–27	35.2	1.80	22.8
Vernon Fine Sandy Loam							
0–3	8.0	11.2	30.2	10–27	27.0	2.66	13.8
3–10	12.0	7.24	19.0	27–58	32.2	2.08	24.7

TABLE 1.—*Continued.*

Depth in inches	Clay per cent content	Clay ratio	Erosion ratio	Depth in inches	Clay per cent content	Clay ratio	Erosion ratio
			Kirvin Fine Sandy Loam				
0–12	8.5	10.3	50.2	51–63	35.4	1.820	10.7
12–24	60.9	0.611	7.2	63–75	9.2	9.82	16.7
24–51	53.4	0.870	7.1	—	—	—	—
			Memphis Silt Loam				
0–8	13.4	6.46	65.2	8–28	30–8	2.24	23.3
			Orangebury Fine Sandy Loam				
0–16	9.9	9.09	50.9	72–96	16.2	5.11	22.4
16–72	23.0	3.35	12.4	—	—	—	—
			Clinton Silt Loam				
0–8	19.1	4.02	57.7	32–44	22.4	3.44	41.7
8–20	24.3	3.09	31.0	44–60	23.2	3.34	24.3
20–32	27.0	2.67	35.5	—	—	—	—
			Shelby Loam				
0–7	24.3	3.01	37.4	24–36	41.7	1.30	24.4
7–24	42.5	1.31	22.3	—	—	—	—
			Muskingum Silt Loam				
0–7	28.4	2.42	42.1	25–46	28.3	2.38	41.9
8–18	37.1	1.62	19.9	47–72	30.4	2.24	59.6
18–24	34.8	1.75	23.1	—	—	—	—

An examination of the general data presented in Table 1 reveals the fact that the clay ratio varies greatly in the different soils, ranging from 0.517 to 11.2. It is smallest in soils which are considered to be non-erosive, such as the Nipe clay, Division clay loam, Aikin silty clay loam, etc., and greatest in soils which are considered to be very erosive, such as the Kirvin fine sandy loam, Clinton silt loam, Vernon fine sandy loam, Shelby loam, etc. Stickiness and cementing tend to produce the same effect.

By comparing the clay ratio with the erosion ratio, it is seen that, with few exceptions, both ratios tend to run parallel in the same soils and they both tend to indicate about the same thing in regard to the possible behavior of soils towards erosion. This general agreement between these two ratios suggests the possibility that the clay ratio might be employed as a criterion of erosion as well as the erosion ratio. Where the two ratios disagree strongly, it cannot be said at present which one is the more nearly correct. This will have to be proved by future investigations and observations.

As is well recognized, field soil erosion is influenced by a great number of factors. The clay ratio and the erosion ratio aim to take into account only the soil factor and to indicate to what relative degree the various soils would be susceptible to erosion under the same conditions. On this basis and understanding, these two ratios should be of value and help in examining soils as to their possible susceptibility to erosion. If by further studies and observations it is proved that the clay ratio is as good or better a single criterion of erosion as the erosion ratio, then the clay ratio should be more desirable to

use for the following reasons: (a) It is based upon logical and scientific principles; and (b) it is simple and rapid to obtain, being completed in about an hour with very little effort (9), while it requires several days to obtain the erosion ratio which involves the extraction of the soil colloids, the determination of vapor adsorption, moisture equivalent, mechanical analyses, and dispersion.

SUMMARY

The $\frac{\text{Sand} + \text{Silt}}{\text{Clay}}$ ratio in soils is suggested in this paper as a possible criterion of judging the relative susceptibility of soils to erosion.

This ratio is designated as the clay ratio. It was compared with the erosion ratio by using the same soils and the same mechanical analyses of these soils as reported by the U. S. Bureau of Chemistry and Soils. The comparison shows that with few exceptions the two ratios agree fairly well in indicating the general susceptibility of soils to erosion.

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THE TEMPORARY INJURIOUS EFFECT OF EXCESSIVE LIMING OF ACID SOILS AND ITS RELATION TO THE PHOSPHATE NUTRITION OF PLANTS[1]

W. H. PIERRE AND G. M. BROWNING[2]

IT has been well established that the use of excessive amounts of lime on certain soils may cause detrimental effects on plant growth, at least temporarily. These detrimental effects, which shall be referred to in this paper as "overliming injury", have in some cases been characterized by a chlorotic condition of the plant and have been found to be caused by a deficiency in the soil of soluble manganese (8, 20, 25, 36),[3] or of iron (6, 9, 37). In other investigations, however, chlorosis has not necessarily accompanied decreased yields (12, 21, 22, 29), and the cause for the overliming injury has not been well established. There is some evidence that excessive liming may result in decreasing the availability of soil potassium (3, 4, 17). It has also been found that liming often decreases the efficiency of the less available phosphate fertilizers, such as bone meal and rock phosphate (10, 31, 32). On the other hand, there is considerable evidence that liming increases phosphate solubility in soils (7, 11, 24, 27, 35), although there are some conflicting data on this point (1, 2, 12, 14).

Midgely (21) has reviewed the literature on the general subject of overliming injury and has studied the possible causes of this condition on overlimed Vermont soils. He found that large additions of organic matter or of calcium silicate were effective in reducing the injury and concluded that neither high pH, the lack of available nutrients, nor the accumulation of nitrites could explain the injury, but that the accumulation of large amounts of calcium salts was probably a contributing factor. In a recent paper published since the present investigation was completed, Midgely and Weisner (22) reported beneficial effects from additions of large amounts of superphosphate; but since they obtained severe injury with flax in the early seedling stages of growth, they concluded that, "the severe injury is not to be attributed to insufficiency of available plant nutrients but rather to some toxic condition, since the nutrients already present in the seeds should provide for a fairly good growth."

The problem of overliming injury has been under investigation at the West Virginia Experiment Station for several years, and it has been found that a temporary decreased growth of crop may result on some soils even when the reaction is considerably below pH 7.0.

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[3]Figures in parenthesis refer to "Literature Cited," p. 757.

In 1930, pastures to which ground limestone was added at the rate of approximately 1.5 tons per acre or in amounts calculated to bring the surface 3 inches of soil to pH 6.0, showed poorer growth than where no lime was used. In the same year alfalfa grown in large tile containers in the field yielded 29% less where the soil was limed to pH 7.2 than where it was limed to pH 6.0. No depression in growth, however, was obtained after the first year. These results have been confirmed by other field observations and by more thorough tests conducted in the greenhouse; and, as shall be seen by the following experiments, the injurious effects of overliming have been found to be associated with a disturbed phosphate nutrition of the plants.

EXPERIMENT I. STUDIES OF GROWTH OF ALFALFA ON SOILS LIMED TO DIFFERENT pH VALUES IN THE GREENHOUSE

In the fall of 1929 nine bulk samples of soils varying in pH from 4.4 to 5.6 were brought to the greenhouse from different sections of the state for a study of the effect of varying degrees of soil acidity on the growth of alfalfa. Each soil was screened, thoroughly mixed, and definite amounts placed in 2-gallon glazed, earthenware pots. Precipitated calcium carbonate was added to bring duplicate pots of each soil to different pH values. In the case of four of the soils which had original pH values above 5.0 (Nos. 504, 505, 509, and 510) one of the treatments consisted of sulfuric acid. After remaining at approximately optimum moisture content for 5 months, all pots were fertilized with muriate of potash at the rate of 100 pounds per acre and monocalcium phosphate at a rate equivalent to 100 pounds P_2O_5 per acre.

Since the detailed results of this experiment will be reported elsewhere, only the more pertinent data will be presented here. Fig. 1 gives the total yields from the three cuttings obtained in 1930. It will be noted that, with one exception, all soils gave considerably lower yields when limed to pH values slightly above 7.0 than where limed to lower pH values, the average decrease in yield being 46%. In most cases the decreased yield from high amounts of lime was considerably more pronounced for the first than for the second and third cuttings. This was especially true where overliming injury was obtained with the first cutting on soils limed to pH values slightly below 7.0. Thus, of the seven soils which were brought to pH values between 6.5 and 7.0, six showed overliming injury at such reactions with the first cutting but only two of the soils did so with the third cutting. When limed to pH values slightly above 7.0, eight of the nine soils continued to show overliming injury with the second and third cuttings.

After removing the third cutting the soils were allowed to remain dry for approximately 6 months after which time they were refertilized as in 1930 and reseeded to alfalfa. The total yields of the three cuttings are shown in Fig. 2. The point of special interest is that with five of the soils the yields were highest at the highest pH values, and that with the other soils the overliming injury at high pH values was much less than in 1930.

No indication was obtained in this experiment as to the immediate cause of the overliming injury. In view of later results, however, it

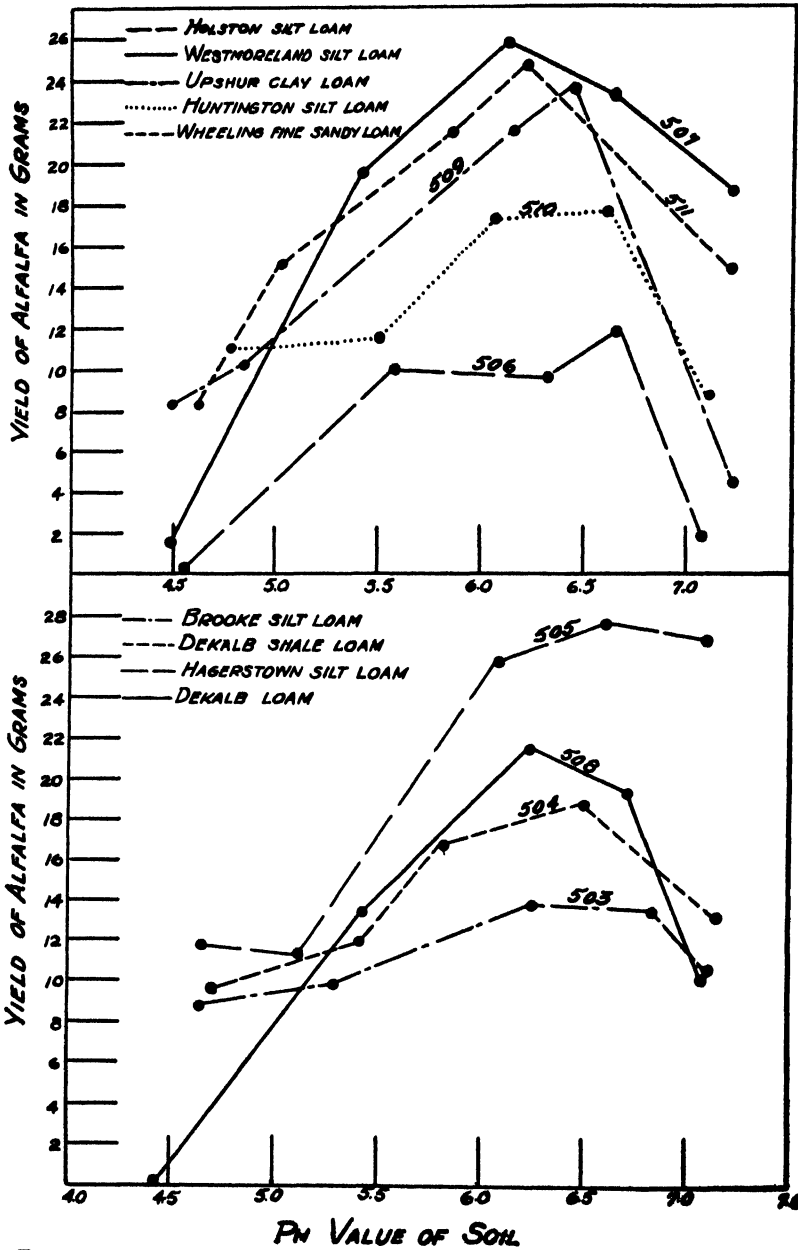

FIG. 1.—The relationship between yield of alfalfa and pH value of soils during the first year after liming (1930).

might be mentioned that the soil with which no injurious effects were obtained from excessive liming, the Hagerstown silt loam, is the most productive soil of the group and the only one which showed no response to phosphorus fertilization. The plants injured from the ex-

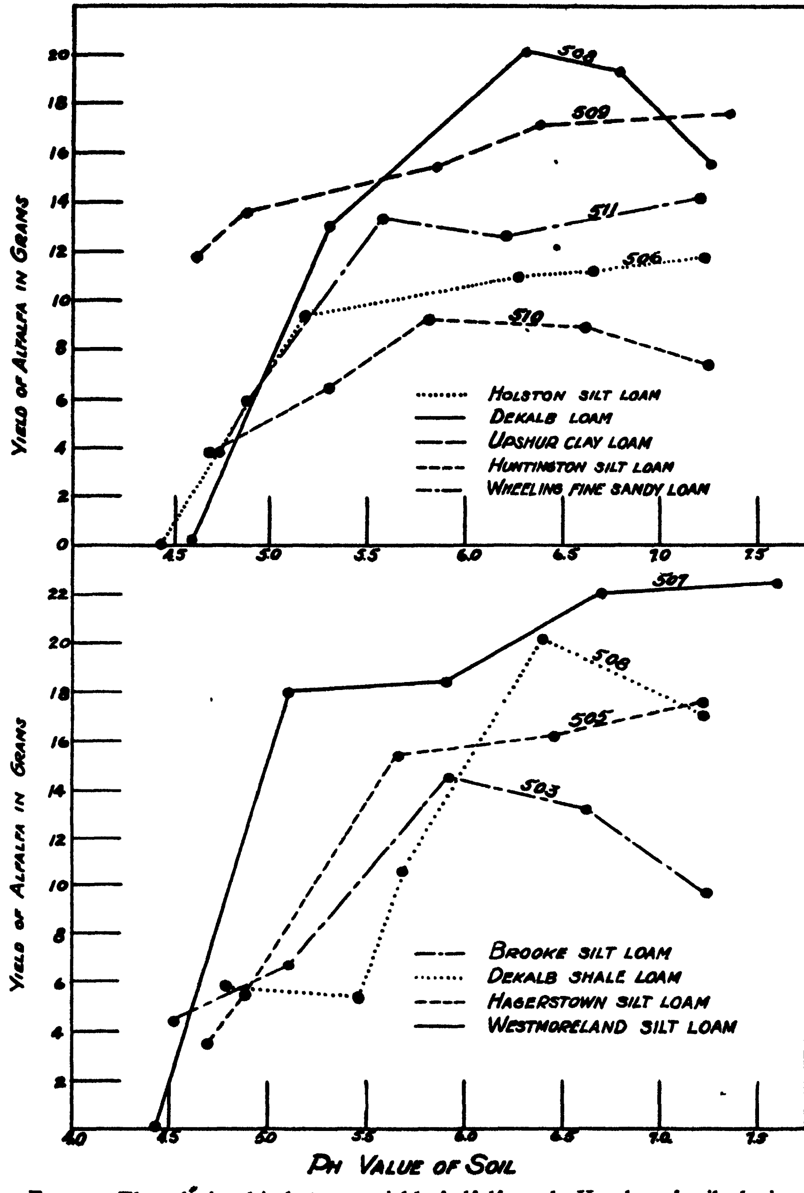

FIG. 2.—The relationship between yield of alfalfa and pH value of soils during the second year after liming (1931).

cessive liming of the soils were stunted and telescoped in appearance. They were not chlorotic, however, but during the latter stages of growth were actually darker green in color than the normal plants.

The results of this experiment emphasize two points, first, that overliming injury can be obtained on many acid soils of West Virginia; and second, that the injury is of a temporary nature. The latter is in agreement with the results of Midgely (21) and Scarseth and Tidmore (29).

EXPERIMENT II. STUDIES OF DIFFERENT SOIL TREATMENTS IN OVERCOMING LIMING INJURY TO CORN IN 1932

Although the injury from excessive liming with alfalfa was not accompanied by chlorosis, it seemed desirable to study the possible beneficial effect of various elements the lack of which had previously been found to be associated with the chlorotic type of liming injury. A large sample of Dekalb loam of approximately pH 4.5 was brought to the greenhouse, thoroughly mixed, screened, and 7,000-gram portions of the dry soil placed in 28 2-gallon pots. To all pots except six, calcium carbonate or different mixtures of calcium and magnesium carbonate were added in sufficient amounts to bring the soil to pH 7.5. Two pots remained unlimed, two were limed with calcium carbonate to pH 6.5, and the other two with equivalent amounts of calcium and magnesium carbonate to pH 6.5. After liming, the soils were kept at approximately optimum moisture content for 6 weeks, after which time they were fertilized and planted to corn.

The fertilization consisted of a uniform application to all pots of nitrate of soda, superphosphate, and muriate of potash at the rates of 400, 500, and 100 pounds per acre, respectively. In addition, certain pots which had been limed to pH 7.5 with calcium carbonate received one of the following treatments, expressed in pounds per acre: 500 pounds KCl; 100 pounds $MnSO_4$; 500 pounds KCl + 100 pounds $MnSO_4$; 50 pounds iron as $FeSO_4$; 50 pounds iron as iron humate prepared from coal; and humic acid in amounts equivalent to the humic acid found in iron humate.

Between 2 and 3 weeks after planting the corn the leaves of most of the plants from the limed pots started to turn pale green to slightly purplish in color. This was true with soils limed to pH 6.5 as well as with those limed to pH 7.5, except where a mixture of calcium and magnesium carbonate had been added. Thereafter, the injury gradually became more pronounced and the leaves on many plants became distinctly purplish in color. The plants on the acid, unlimed soil had a chlorotic appearance characteristic of acidity injury. All plants were harvested after 5 weeks and their dry weights determined. At pH 6.5 a mixture of equivalent amounts of calcium carbonate and magnesium carbonate gave 9.6 grams of oven-dry material as compared to 7.3 grams where calcium alone was used. When limed to pH 7.5 the substitution of one-fourth, one-half, and three-fourths of the calcium carbonate with an equivalent amount of magnesium carbonate resulted in a yield of 8.1, 6.5, and 4.4 grams, respectively, as compared to 6.3 grams where calcium carbonate alone was used.

The yield data also substantiated the observations made during growth that large amounts of potassium chloride, or $MnSO_4$, ferric humate, or humic acid had no effect in reducing liming injury.

After removing the corn crop, the soil in all pots was refertilized with superphosphate at the rate of 500 pounds per acre and the pots seeded to alfalfa. Regardless of treatment the alfalfa made only fair growth where the soil was limed to pH 6.5 and very poor growth when limed to pH 7.5. The plants were therefore removed after 5 weeks.

Since the corn plants had shown a definite purplish color characacteristic of phosphate deficiency, it seemed desirable to continue the study on this soil by giving the pots additional differential treatment,

FIG. 3.—The effect of silica gel and of phosphate fertilizers on overliming injury to corn 32 days after planting. Pot No. 18, check, 19.0 grams corn; No. 7, silica gel, 38.8 grams corn; No. 9, additional phosphorus as $CaH_4(PO_4)_2$, 37.0 grams corn; and No. 11, additional phosphate as KH_2PO_4, 37.9 grams corn.

particularly with regard to phosphorus. The soil cultures which had been limed to pH 7.5 with calcium carbonate and had received differential treatment were thoroughly mixed together, then placed back in the pots and given the treatments shown in Table 1. Corn was planted on July 9.

After about 2 weeks the plants began to show slight differences in appearance and growth and within the following 2 weeks these differences became very pronounced. Where no differential treatment was applied or where potassium or magnesium sulfate was added, the plants made very poor growth and the leaves turned a purplish color, characteristic of phosphate starvation. On the other hand, the plants grown on soil receiving silica gel or large amounts of calcium or potassium phosphate made good growth (Fig. 3) and

TABLE 1.—*The yield of corn and the solubility of PO_4 in Dekalb loam (soil No. 609) limed to pH 7.5 and receiving different treatments.*

Pot Nos.	Differential treatments in lbs. per acre	Average yield of corn (oven-dry weight), grams	Inorganic PO_4		Available PO_4 (Truog method), p.p.m.
			Water extract (1:5 soil basis), p.p.m.	Soil solution, p.p.m.	
1–2	Check (no lime)	23.5	0.37	0.13	94
17–18	None	19.0	0.65	0.32	128
7–8	4,000 lbs. silica gel	38.8	1.21	0.48	127
9–10	200 lbs. P_2O_5 as $CaH_4(PO_4)_2$	37.0	1.17	0.37	254
11–12	200 lbs. P_2O_5 as KH_2PO_4	37.9	1.22	0.52	215
13–14	K_2SO_4*	22.7	0.60	—	138
15–16	$MgSO_4$*	20.8	0.63	—	140

*K_2SO_4 was applied at such a rate as to add the same amount of potassium as was added in pots 11 and 12. $MgSO_4$ was added at such a rate as to add the same amount of sulfur as in pots 13 and 14.

had normal green color. Table 1 gives the yields of corn harvested on September 2, as well as the concentration of inorganic phosphate in the displaced soil solution (5, 23) and soil extract (23, 26), and the acid-soluble phosphate by the Truog (33) method of samples taken after the removal of corn. These data show that 4,000 pounds of silica gel per acre and phosphate fertilizers equivalent to 200 pounds of P_2O_5 per acre practically doubled the phosphate concentration in the soil extract, and also doubled the yields of corn.

The remaining pots of soil from the original series were also continued and cropped similarly to those just described. The additional fertilizer treatments, the yield of corn, the concentration of water-soluble phosphate, and the phosphate in the displaced soil solution are given in Table 2. The data show that the soil limed to pH 6.5 with equivalent amounts of calcium and magnesium carbonate gave higher yields than where calcium carbonate alone was used. Likewise, the addition of sodium phosphate to the soil limed with only calcium carbonate decidedly increased the yield. When limed to pH 7.5 the yields were increased where the proportion of magnesium to calcium carbonate was increased, even though the pH was slightly higher where the larger amounts of magnesium carbonate were used. Likewise, the water-soluble phosphorus was increased. When three-fourths of the calcium carbonate was replaced by magnesium carbonate, the phosphorus was approximately doubled in the soil extract and tripled in the soil solution. It is thus evident from the data presented in Tables 1 and 2 that treatments which increased the soluble phosphate in the soil overcame or tended to overcome the liming injury, regardless of whether the treatment consisted of additions of large amounts of phosphate fertilizer, of silica gel, or of substitution of part of the calcium carbonate by magnesium carbonate. Sodium phosphate, however, was not beneficial at high pH values, even though it increased the water-soluble phosphate. Although the reason for this is not clear, it is probable that the sodium was either

directly or indirectly toxic under these conditions. It should be noted also that, although the overliming injury was overcome by increasing the amount of phosphate in the soil solution, liming to high pH values did not decrease the concentration of water-soluble phosphate in the soil.

TABLE 2.—*The yield of corn and the solubility of phosphate in Dekalb loam (soil No. 609) receiving different proportions of calcium and magnesium carbonate.*

Pot Nos.*	Ratio of $CaCO_3$ to $MgCO_3$ (added at beginning of experiment)	pH value after liming	Average yield of corn (oven-dry weight), grams	Inorganic PO_4		Available PO_4 (Truog method), p.p.m.
				Water extract (1:5 soil basis), p.p.m.	Soil solution, p.p.m.	
1–2	——	4.55	23.5	0.37	0.13	94
3–4	1:0	6.45	17.4	0.53	0.19	77
5–6	½:½	6.45	27.5	0.68	0.23	85
25–26	1:0	6.60	25.2	1.22	0.41	164
27–28	1:0	7.55	19.0	1.52	0.39	212
19–20	¾:¼	7.55	22.7	1.69	0.43	206
21–22	½:½	7.90	26.4	2.03	0.71	212
23–24	¼:¾	7.80	30.1	2.98	1.16	205

*Pots numbered 19 to 28, inclusive, received additional phosphate as NaH_2PO_4 at a rate equivalent to 160 pounds P_2O_5 per acre before planting corn.

The data in the previous experiment do not show the extent of the liming injury so far as decreased yields are concerned, since the unlimed soil was too acid to give optimum growth and the lowest rate of liming caused injury. To show the extent of injury a supplementary experiment was conducted using soil from the same source. After liming the soil in duplicate pots with calcium carbonate to obtain pH values of approximately 5.5, 6.5, and 7.5, the pots were allowed to remain at approximately optimum moisture for 1 month. Superphosphate, muriate of potash, and urea were then added at the rates of 500, 135, and 150 pounds per acre, respectively, and the pots planted to corn. Good growth was obtained at pH 5.5, but the characteristic purplish leaf color and poor growth were obtained at pH 6.5 and 7.5. A photograph of the plants when they were 2 months old is shown in Fig. 4.

EXPERIMENT III. LIMING INJURY STUDIES WITH RAPE AND CORN, 1932–33

This experiment was started with the purpose of obtaining further information particularly in regard to the use of different liming materials and to the effect of overliming injury on plant composition. The soil was obtained from the same field as in the previous experiment. Four different liming materials were used, namely, pure calcium carbonate, calcium limestone, dolomitic limestone, and calcium silicate. These were added at two different rates, 16 2-gallon pots being limed to approximately pH 5.8 and an equal number being limed to approximately pH 7.0. The liming treatments as well as the additional differential treatments with superphosphate and silica gel are shown in the first two columns of Tables 3 and 4. The high-

calcium limestone and the dolomitic limestone were both of approximately the same degree of fineness, 25% being composed of 60 to 100-mesh separates, and 75% of material finer than 100-mesh. The calcium silicate was a commercial by-product obtained from the Electric Smelting and Aluminum Company of Sewaren, N. J. According

FIG. 4.—Growth of corn on Dekalb loam soil limed to different pH values, plants 2 months old. Pot No. 7, pH 4.55, 38.1 grams corn; No. 23, pH 5.5 o, 80.9 grams corn; No. 40, pH 6.60, 57.6 grams corn; No. 55, pH 7.55, 19.4 grams corn.

TABLE 3.—*Yield of rape on a Dekalb loam (soil No. 647) limed to two different pH values and receiving different treatments.*

Soil treatment*		Yield (dry weight), grams		PO_4 in 1:5 water extract (soil basis), p.p.m.		Ca in soil solution, p.p.m.	
Liming materials	Superphosphate, lb. per acre	A†	B	A	B	A	B
$CaCO_3$	None	—	5.3	0.15	0.16	494	882
$CaCO_3$	500	9.7§	7.0	0.18	0.18	308	912
$CaCO_3$	1,000	10.1	8.3	0.25	0.42	—	—
$CaCO_3$	2,500	11.5	10.0	0.60	0.64	623	906
$CaCO_3$‡	500	11.8	9.1	0.30	0.49	319	903
Dolomitic limestone	500	10.8	9.2	0.26	0.37	134	287
Calcium limestone	500	11.5	6.9	0.19	0.22	295	1175
Calcium silicate	500	11.5	10.1	0.31	0.58	226	566

*All pots recei ed a uniform application of nitrogen and potash.
†A refers to medium liming, approximately pH 5.8; B to high liming, approximately pH 7.0.
‡Received silica gel at the rate of 4,000 pounds per acre.
§Some injury from naphthalene fumigation.

to the analysis reported by Scheidt (30), it contained 49.1% CaO, 3.2% MgO, and 6.0% Na_2O. After the liming materials had been allowed to react with the soil for 6 weeks, all pots received a uniform application of muriate of potash at the rate of 100 pounds per acre and urea at the rate of 150 pounds per acre. The superphosphate and silica gel shown in Tables 3 and 4 were also applied at this time. All pots were seeded to rape on October 26.

TABLE 4.—*Yield of corn on a Dekalb soil (soil No. 647) limed to two different pH values and receiving different treatments.*

Soil treatment*		Yield (dry weight), grams		pH values		PO_4 in 1:5 water extract (soil basis), p.p.m.	
Liming material	Superphosphate, lbs. per acre	A†	B	A	B	A	B
$CaCO_3$	None	9.7	2.7	5.75	7.00	0.24	0.23
$CaCO_3$	500	28.7	8.7	5.85	7.05	0.35	0.30
$CaCO_3$	2,500	43.5	34.5	5.70	6.95	1.58	1.60
$CaCO_3$‡	500	31.5	20.6	5.65	6.95	0.71	0.59
Dolomitic limestone	500	33.1	27.2	5.75	6.85	0.52	0.47
Calcium limestone	500	26.4	8.8	5.80	7.05	0.33	0.27
Calcium silicate	500	30.4	20.2	5.85	7.10	0.49	0.68

*All pots received a uniform application of nitrogen and potash.
†A refers to medium liming, approximately pH 5.8; B to high liming, approximately pH 7.0.
‡Received silica gel at the rate of 4,000 pounds per acre.

PLANT GROWTH

After approximately 3 weeks the plants in the cultures limed to pH 7.0 were making much poorer growth than those limed to pH 5.8, with the exception of those receiving the high rate of superphosphate, the dolomitic limestone, or the calcium silicate. These differences in growth became even more apparent during the next 4 or 5 weeks, except that the plants from the cultures of pH 7.0 receiving silica gel recovered from the overliming injury. Thereafter a long period of cloudy weather caused the plants to make very slow growth, and the differences in growth between the best and poorest plants decreased. The rape was harvested on January 17, and the oven-dry weights are reported in Table 3. No significant differences in yield were obtained from the different liming treatments on soil limed to a pH of approximately 5.8. Unfortunately, with the medium liming series naphthalene fumigation caused severe injury to the plants of the "no phosphorus" treatment and slight injury to the plants of the "calcium carbonate-regular phosphorus" treatment. When the soil was limed to pH values of approximately 7.0 significant differences in yield were obtained with the different liming materials, the yield with dolomitic limestone and calcium silicate being considerably greater than with calcium carbonate or high calcium limestone. Moreover, as in the previous experiment, large amounts of superphosphate or of silica gel materially increased the yield.

After harvesting the rape the soil in each pot was mixed, the plant roots removed, and samples of soil taken for laboratory studies.

The potted soils were then brought to 15% moisture, allowed to stand for 3 to 5 days, and the soil solution displaced (5) from approximately 1-kilogram samples. After displacement the soil samples were placed back in the pots and allowed to dry. The soil in each pot was then thoroughly mixed and refertilized as for the rape crop. Corn was planted on February 18. A top-dressing of nitrate of soda at the rate of 300 pounds per acre was applied on April 17, and the corn was harvested on May 12. The yield data are given in Table 4.

With "medium liming" there was little difference in the yields as a result of the different liming materials, but with "high liming" marked differences in growth were obtained, the yield with dolomitic limestone and calcium silicate being about three times as high as with calcium limestone and calcium carbonate. Likewise, when large amounts of silica gel or of superphosphate were applied in addition to calcium carbonate, the yield was increased approximately two to four times. As in the other experiments, the yield data were closely related to the extent of purpling of the leaves during growth.

SOIL STUDIES

The pH values and the content of inorganic phosphate in the soil extract of samples taken after the removal of each crop are given in Tables 3 and 4. As in the previous experiment, silica gel materially increased the concentration of water-soluble phosphates. Likewise, calcium silicate and dolomitic limestone additions resulted in much higher concentrations of water-soluble phosphorus than did additions of calcium carbonate and high-calcium limestone. These differences, it will be noted, were obtained both with the medium and high rate of liming. Another point of considerable interest is the fact that with the exception of the cultures receiving calcium silicate, there was no consistent difference in the water-soluble phosphate of cultures receiving different amounts of the same liming material. This is somewhat different from the results obtained in Experiment II where liming to pH 7.5 resulted in a higher soluble phosphate concentration than liming to pH 6.5. It is apparent from both experiments, however, that the injury from overliming is not associated with a lower amount of water-soluble PO_4 in the soil extract. This is further shown by data obtained from a study of soil samples taken immediately before the first fertilization in Experiment I and presented in Fig. 5. Although all of these soils showed considerable liming injury with alfalfa, in only one out of the three was there a significant decrease in water-soluble phosphate at high pH values.

As shown in Table 3, the calcium concentration is much higher in the displaced soil solution of soils limed to pH 7.0 than in those of soils limed to pH 5.8. Additions of silica gel or large amounts of superphosphate which materially decreased overliming injury did not reduce the calcium concentration of the soil solution. This indicates that high concentrations of calcium are not directly related to the poor growth obtained, or else that any injurious effects which might be due to high amounts of calcium are overcome by increasing the amounts of available phosphorus.

PLANT ANALYSIS

As will be seen in Table 5, the plants grown on the heavily limed soil are considerably higher in calcium on the dry plant basis than those grown on the soils limed to approximately pH 5.8. The percentages of phosphorus on the same basis vary but slightly. The calcium-phosphorus ratio, however, is much higher in the plants grown on the heavily limed soil. Moreover, with the high liming treatments, there appears to be a relationship between yields and calcium-phos-

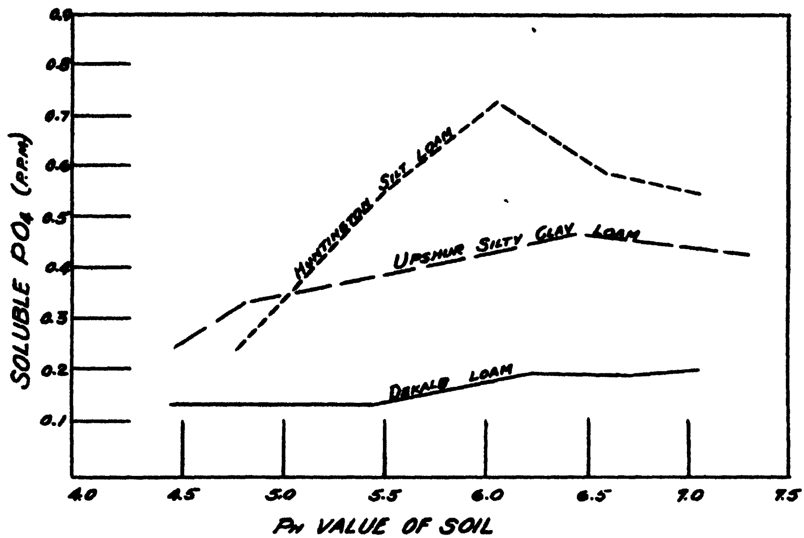

FIG. 5.—The relationship between the pH value and the water-soluble phosphate of soils recently limed to different pH values.

TABLE 5.—*The percentage of calcium, magnesium, and phosphorus in corn plants grown on a Dekalb soil receiving different amounts of liming materials and other treatments.*

Soil treatment		Ca %		Mg %		P %		Ca:P ratio	
Liming material	Superphosphate, lbs. per acre	A*	B	A	B	A	B	A	B
$CaCO_3$.....	None	1.250	1.98	0.225	0.055	0.143	0.092	4.5	11.1
$CaCO_3$.....	500	0.806	1.64	0.159	0.104	0.121	0.119	3.4	7.1
$CaCO_3$.....	2,500	0.745	1.07	0.078	0.044	0.123	0.101	3.2	5.5
$CaCO_3$†	500	0.867	1.30	0.096	0.138	0.104	0.102	4.3	6.6
Dolomitic limestone.	500	0.378	0.53	0.580	1.018	0.103	0.099	1.9	2.7
Calcium limestone.	500	0.771	1.81	0.175	0.197	0.113	0.113	3.5	8.3
Calcium silicate...	500	0.590	1.20	0.355	0.520	0.123	0.098	2.5	6.3

*A refers to medium liming, approximately pH 5.8; B to high liming, approximately pH 7.0.
†Soil received silica gel at rate of 4,000 pounds per acre.

phorus ratio if the cultures receiving the magnesium-containing liming materials, *viz.*, dolomitic limestone and calcium silicate, are excluded.

In considering plant analysis data it should be emphasized that percentage composition based on the dry plant weight is oftentimes inadequate, since the ash content of plants depends to some extent on the size of the plants or their stage of development. Thus, stunted plants are often found to contain a higher content of ash than those making normal growth. It seemed desirable, therefore, to determine the percentage of ash in these plants and to express the content of calcium, magnesium, and phosphorus on the ash basis. These data are given in Table 6. It will be first noted that plants making poor growth due to a lack of phosphorus, or plants stunted as a result of liming injury have a much higher percentage of ash than those making normal growth. As a consequence, the percentage of calcium on the ash basis is not much different for plants receiving near optimum amounts of lime than for corresponding plants grown on the same soil receiving excessive amounts of liming materials. The percentage of phosphorus, however, is lower in the ash of plants grown on the soil receiving the large amounts of liming materials, a point that may be of some significance in view of the fact that overliming injury was found to be overcome by treatments which increased the water-soluble phosphorus in the soil.

TABLE 6.—*The percentage of calcium, magnesium, and phosphorus in the ash of corn plants grown on a Dekalb soil receiving medium and high liming treatments.*

Soil treatment		Ash %		Ca %		Mg %		P %	
Liming material	Superphosphate, lbs. per acre	A*	B	A	B	A	B	A	B
$CaCO_3$........	None	9.14	—†	13.7	—	2.47	—	1.57	—
$CaCO_3$........	500	4.36	9.00	18.5	18.3	3.63	1.16	2.78	1.32
$CaCO_3$........	2,500	3.69	4.28	20.5	25.0	2.12	1.03	3.34	2.36
$CaCO_3$‡........	500	5.21	7.58	16.6	17.2	1.84	1.82	2.00	1.35
Dolomitic limestone........	500	3.95	5.50	9.6	9.6	14.70	18.50	2.61	1.80
Calcium limestone........	500	4.09	10.81	18.9	16.7	4.28	1.82	2.76	1.04
Calcium silicate	500	4.58	7.00	12.9	17.1	7.77	7.45	1.69	1.40

*A refers to medium liming, approximately pH 5.8; B to high liming, approximately pH 7.0.
†Insufficient plant material left for determination of ash.
‡Received silica gel at rate of 4,000 pounds per acre.

With the exception of the plants receiving dolomitic limestone or calcium silicate treatments, the percentage magnesium on the ash basis is much lower where the plants received excessive amounts of liming materials. It is also interesting to note that a good growth of corn was obtained at high pH values when the calcium-magnesium ratio in the plant varied from about 23 to 1 to as low as 0.5 to 1.0.

GENERAL DISCUSSION

The beneficial effect of large amounts of phosphates in overcoming liming injury obtained in this study is in agreement with results obtained by Scarseth and Tidmore (29) in some recent studies on phosphate fixation. Studying the effect of different sources of phosphates when applied at rates varying from 48 to 144 pounds P_2O_5 per acre, they obtained less decreased yields of sorghum from liming to pH 6.5 where the larger rate of phosphorus fertilizers had been applied. Zimmerly (37) likewise found that heavy phosphate fertilization reduced the injury from chlorosis with snap beans grown at pH values slightly below neutrality, although he concluded from his plant analysis data that the chlorosis was not attributable to phosphorus deficiency.

In the present study it has been established that the injury to plant growth obtained by overliming an acid Dekalb loam soil is largely overcome by the additions of large amounts of phosphate fertilizer or by other soil treatments which increase the water-soluble phosphate in the soil. Thus, the beneficial effect of silica gel and of calcium silicate can be explained by the fact that the water-soluble phosphorus in the soil was, in general, more than doubled, possibly due to the formation of calcium silico-phosphate compounds (19, 28), which, according to Körber and Trömel (15), have a high solubility in ammonium citrate solution. Likewise, the beneficial effect obtained by substituting magnesium carbonate for a part of the calcium carbonate or by the use of dolomitic limestone instead of high calcium limestone is no doubt due to the formation in the soil of magnesium phosphate compounds of relatively high solubility. In view of these results it can be concluded that plants grown on the excessively limed soils studied made poor growth due to a disturbed phosphate nutrition. It is not readily evident, however, why the plants suffered from a lack of available phosphorus on such overlimed soils, especially in view of the fact that the concentration of water-soluble phosphorus in the soil was in some cases increased and in others not affected by excessive liming. It would appear either that the concentration of water-soluble phosphorus in the soil extract is not a true measure of phosphate availability, or else that under the conditions brought about in the soil by overliming, plants require larger amounts of soluble phosphorus for normal growth than where smaller or optimum amounts of lime are used. McGeorge (18) concluded from electrodialysis studies that plants require more soluble phosphate on alkaline than on neutral or slightly acid soils for normal growth, whereas Loew (16), Truog (34), and others have suggested a relationship between the calcium-magnesium balance in the soil solution and phosphate assimilation by plants.

Neither is it clear why the injury to plant growth from excessive liming is only temporary. It was found, however, in a study not reported in this paper that a Dekalb silt loam soil limed to approximately pH 7.0 contained a much higher amount of water-soluble phosphorus after it had been allowed to remain in a pile in the field for a period of 3 years than immediately after liming, and a con-

siderably higher amount than did the unlimed soil similarly treated. This is in agreement with the work of Greenhill (11). This investigator found less response to phosphorus fertilizers 1 year after than immediately after liming, and concluded that heavy additions of lime slowly render available to the plant some of the original reserves of phosphate in the soil.

The results obtained in this investigation, therefore, should not be considered contradictory to the generally recognized principle that the liming of acid soils tends to make the soil phosphates more soluble and available (7, 11, 24, 27, 31, 35). It should be clearly recognized that the immediate effects of liming, especially if in excessive amounts, may be entirely different, so far as the availability of phosphates to plants is concerned, than the ultimate effect; Whereas, plants grown on soils to which large amounts of liming materials have recently been added may show symptoms of phosphate starvation and respond markedly to high phosphate fertilization, this temporary condition is gradually overcome and the lime slowly increases the availability of the soil phosphorus. Karraker's (13) results, showing a delayed effect of liming, are of interest in this connection.

In view of the beneficial effects of additions of silica gel in overcoming overliming injury and in increasing the water-soluble phosphates in the soil, it is believed that one of the important corrective factors under natural conditions is the colloidal silica and silicates present in soils. Other factors, however, are probably involved in the recovery from overliming.

Since overliming injury of the type described in this paper occurs on soils limed to pH 6.5 or even less, it is evident that on sandy soils especially care should be taken in the amounts of lime used at any one time. Although the injury is only temporary and is not likely to be as important under field as under greenhouse conditions, overliming injury to a more or less degree is conceivable under many field conditions. When the lime is applied as a top dressing such as for pastures, it should be realized that the lime moves downward very slowly, and that the surface inch or two of soil, may, therefore, receive a large excess even though the application on the plowed-depth basis is not large. Moreover, in reporting the results of field and especially greenhouse investigations, the amounts and kind of liming material used and the acidity of the soil before and after the applications are made should be considered essential data for a proper interpretation of the results obtained. This would be especially true in case of phosphate availability studies.

SUMMARY

Greenhouse studies were conducted with the purpose of determining the cause of the injurious effects of overliming on plant growth. The results obtained may be briefly summarized as follows:

1. Nine out of 10 acid soils ranging in pH from 4.4 to 5.6 gave poorer growth of alfalfa when brought to pH values near neutrality than when lower amounts of calcium carbonate were used, the average decreased yields when the pH values were slightly above 7.0

being 46%. With five of the nine soils the overliming injury to alfalfa disappeared after the first year.

2. Corn grown on an acid Dekalb loam which had been limed to pH values of approximately 6.5 and 7.5 showed marked injury and developed a light green to purplish color characteristic of phosphorus starvation. Additions of manganese sulfate, magnesium sulfate, ferrous sulfate, iron humate, or large amounts of muriate of potash did not correct this condition. The additions of large amounts of mono-calcium phosphate, mono-potassium phosphate, or silica gel, however, overcame the injury. Likewise the substitution of increasing amounts of magnesium carbonate for calcium carbonate, up to 75%, markedly improved growth and produced normal leaf color where the largest amount was added.

3. The materials that overcame liming injury materially increased the water-soluble phosphate in the soil solution and soil extract.

4. In a comparison of four different liming materials added in sufficient amounts to bring an acid Dekalb loam to pH 7.0, corn and rape made much better growth with dolomitic limestone or calcium silicate than with calcium limestone or calcium carbonate; the plants in the latter cases likewise showed marked symptoms of phosphate deficiency. The differences thus obtained were found to be explained by the larger concentrations of water-soluble phosphate where the dolomitic limestone and calcium silicate sources had been used. When the liming materials were added in amounts to bring the soil to pH 5.8, no liming injury was obtained and there was little difference in growth from the use of the various liming materials.

5. The corn plants grown on the soil limed to pH 7.0 had a higher ash content and a lower percentage of magnesium and phosphorus on the ash basis than plants grown at pH 5.8. Excluding the dolomitic limestone treatment some evidence was obtained of a relationship between the injury from excessive liming and the calcium-phosphorus ratio of plants.

6. It is concluded that the temporary overliming injury obtained in these experiments is due to a disturbed phosphate nutrition.

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THE EFFECT OF DILUTION ON THE SOLUBILITY OF SOIL PHOSPHORUS[1]

HUGH DUKES[2]

SINCE the water-soluble phosphorus in most humid soils is small studies dealing with specific influences of dilution on the behavior of soil phosphorus are limited; yet a number of papers have suggested a possible influence of dilution on the solubility of phosphorus. Hibbard (2)[3] reports that the amount of PO_4 dissolved increases as the volume of solvent is increased up to a high dilution when dilute hydrochloric acid is used as a solvent, but that the concentration remains almost constant where water is used as the solvent, even with a dilution of 100 or more parts of water to 1 of soil. Lohse and Ruhnke (3) report a higher concentration of phosphorus with a 1 to 20 dilution (using a 0.01 m $KHSO_4$ solvent) than a dilution of 1 to 4 or 1 to 50. On the other hand, leaching a garden soil with a solution of $KHSO_4$ having a pH of 2.0 gave the greatest concentration of phosphorus in the first leaching. Bryan (1) reported that the phosphorus concentration of the successive leachates of different soils increased for a time, but a maximum concentration was not reported.

Soluble aluminum, calcium, and iron, as well as other elements, are known to decrease the concentration of phosphorus in the soil solution. In most cases these agents are more abundant than phosphorus and thus render phosphates insoluble. But in sandy soils with less quantities of fixing agents the conditions are different.

That calcium in the soil decreases the solubility of phosphorus is confirmed by the work of McGeorge (4) and others. McGeorge (4) reports that crops respond to phosphate fertilizers on calcareous soils even though they contain a high content of phosphates. Moreover, leaching such soils usually decreases the response of phosphate fertilizers.

In successive leachates of a soil Parker and Tidmore (5) found an increase in phosphorus and a decrease in calcium. Teakle (6) found that additions of ammonium oxalate to the soil solution greatly increased the phosphorus concentration.

The object of this study was to determine the effect of dilution (with water) on the solubility of phosphorus in sandy soils.

EXPERIMENTAL METHODS

The study was conducted under laboratory conditions, using a number of soils varying in texture and known to have a wide range in water-soluble phosphorus. The study consisted primarily in diluting the soils with varying amounts of distilled water and determining the phosphorus in the filtered solutions. The di-

[1]Contribution from the Department of Soils, University of Florida, Gainesville, Fla. Received for publication June 3, 1935.

[2]Graduate Student. The writer wishes to express his appreciation to Dr. O. C. Bryan for his suggestions and criticisms rendered in the preparation of this manuscript.

[3]Figures in parenthesis refer to "Literature Cited," p. 763.

lutions were made in erlenmeyer flasks, using 5-gram portions of soil and amounts of water varying from 2.5 cc to 75 cc. The contents of the flasks were shaken for 15 minutes and filtered. The phosphorus in the filtrates was determined colormetrically, using Truog's (7) method.

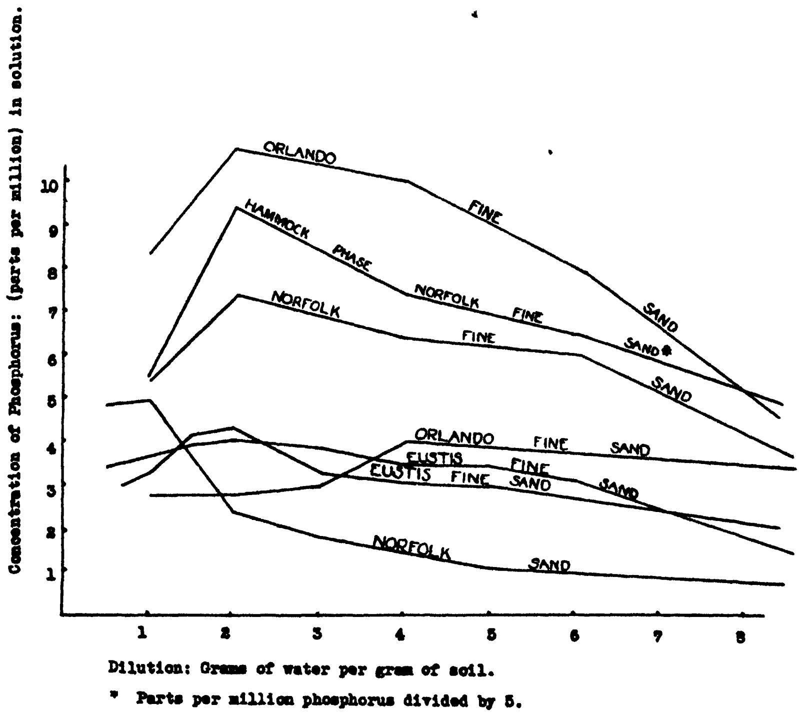

FIG. 1.—The effect of dilution on the solubility of soil phosphates.

RESULTS

The results shown in Fig. 1 indicate that the concentration of phosphorus in the soil solution increases on dilution for a time then gradually decreases with further dilution. This seemed to be true regardless of soil texture and content of phosphorus. In order to determine the influence of time of shaking the soil and water on the solubility of the phosphorus, two soils varying in phosphorus content were shaken for different periods of time (10 minutes, 30 minutes, 3 hours, and 15 hours). They were then filtered and the filtrates examined for phosphorus. The results are given in Table 1. Here it will be seen that the time of shaking influenced the total phosphorus in solution, but the proportions are not greatly altered. Lohse and Ruhnke (3) found this to be true, but, at a larger dilution than was used in this study. While Hibbard's (2) results do not agree with these results entirely, he obtained an increase in soluble phosphorus on dilution with a dilute acid.

TABLE 1.—*The influence of time of shaking on the solubility of soil phosphates.**

Soil used	Phosphorus in solution at intervals indicated, p.p.m. of P.			
	After 10 min.	After 30 min.	After 3 hrs.	After 15 hrs.
Orlando fine sand.	23.25	27.50	33.75	41.25
Bladen fine sand. .	2.00	2.12	2.25	2.50

*Ratio of soil to water, 1 : 5.

Although it is commonly accepted that calcium has a positive effect on the solubility of soil phosphorus, no definite relation has been established. In order to ascertain the effect of calcium on the solubility of phosphorus in the soil solution, the soluble phosphorus and calcium were determined in the leachates of a number of soils. For this purpose, the soils were placed in tubes and leached in a manner similar to rainfall. The calcium was determined by the standard oxalate method and the phosphorus as previously indicated. The results are given in Table 2.

From Table 2 it may be seen that as the concentration of the calcium decreases, the concentration of the phosphorus increases but not in chemical equivalents. As a rule, the greatest concentration of phosphorus occurred at the first disappearance of calcium. Beyond this, the phosphorus decreased. It is interesting to note that this was true with high or low concentrations of calcium and phosphorus in the soil solutions.

These results seem to confirm those of Bryan (1) and Teakle (6) regarding the behavior of phosphorus on dilution. It would appear from these results that the phosphorus was not necessarily in combination with calcium. At least they do not occur in chemical equivalents. In all probability some of the soluble phosphorus was in combination with sodium, potassium, and ammonium as well as hydrogen in acid soil. The exact form would be difficult to determine. It is true that the method for determining calcium is not as delicate as that for phosphorus; however, the results should be in order. But the break in the concentration of phosphorus in the soil solution is quite evident regardless of soil used. This "break" or change in concentration seems to be due to the calcium present. It is of interest to note that the total amount of phosphorus in the soil solution is not directly related to the amount of calcium in the solution.

SUMMARY

Water extracts were made of a number of soil types, using with each type one part of soil to amounts of water varying from ½ to 15 parts. These extracts were analyzed for phosphorus. The results show that the concentration of phosphorus in the extracts increased with dilution up to a certain point for each soil, and upon further dilution decreased.

Samples of soil were also leached with distilled water, and the successive leachates analyzed for calcium and phosphorus. The results show that the phosphorus reached its maximum concentration at the point where the calcium first disappears from the leachates.

TABLE 2.—*The depressing effect of calcium on the soluble phosphorus in different soils.*

Successive leachings from 315 grams soil, cc	Concentration of phosphorus and calcium in successive leachings of different soils, p.p.m.							
	Bladen fine sand		Norfolk sand		Norfolk fine sand		Norfolk fine sand	
	P	CaO	P	CaO	P	CaO	P	CaO
25	6.0	2.48	8.0	4.48	11	8.00	4.0	2.45
25	7.5	1.28	9.0	2.12	15	4.50	4.4	2.12
50	8.2	0.00	9.5	0.24	18	1.32	4.2	0.34
50	7.8	0.00	9.7	0.24	21	0.68	4.0	0.28
50	8.0	0.20	9.0	0.00	23	0.04	4.5	0.30
50	7.8	0.00	8.0	0.00	24	0.00	4.9	0.34
50	7.0	0.00	7.0	0.00	20	0.00	5.4	0.14
50	6.5	0.00	—	—	18	0.00	4.7	0.00
50	—	—	—	—	17	0.00	4.6	0.00
50	—	—	—	—	—	—	4.5	0.00
50	—	—	—	—	—	—	4.6	0.00
50	—	—	—	—	—	—	4.4	0.00
50	—	—	—	—	—	—	—	—
	Norfolk fine sand		Orlando fine sand		Bladen fine sand			
	P	CaO	P	CaO	P	CaO		
25	1.0	11.3	15.0	10.72	0.45	6.8		
25	1.5	13.0	18.0	4.52	0.48	3.7		
50	2.1	0.9	27.0	1.00	0.49	2.5		
50	2.6	0.27	30.0	0.08	0.51	1.5		
50	2.9	0.10	28.0	0.00	0.57	0.73		
50	3.2	0.09	25.0	0.00	0.62	0.51		
50	3.0	0.00	22.0	0.00	0.65	0.49		
50	2.7	0.00	—	—	0.65	0.33		
50	2.6	0.00	—	—	0.65	0.15		
50	2.5	0.00	—	—	0.62	0.00		
50	—	—	—	—	0.55	0.00		
50	—	—	—	—	0.57	0.00		
50	—	—	—	—	0.52	0.00		

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NON-ACID-FORMING MIXED FERTILIZERS: II. THE VALUE OF DOLOMITIC LIMESTONE SUPPLEMENTS OF DIFFERENT DEGREES OF FINENESS AS MEASURED BY THE INCREASE IN WATER-SOLUBLE MAGNESIUM IN THE SOIL[1]

J. R. TAYLOR, JR., AND W. H. PIERRE[2]

THE recent development in the manufacture of mixed fertilizers of adding dolomitic limestone in order to make them non-acid forming or to supply available magnesium has raised the question as to the proper fineness of the limestone. From the manufacturer's standpoint there are certain objections to the use of very finely ground material. On the other hand, it is well recognized that the finer a limestone is ground, the quicker it reacts with the soil. In answering the question of proper fineness, therefore, consideration must be given, first, to the need or desirability of having the limestone used in mixed fertilizers react rapidly with the soil, and second, to the rate of reaction of dolomitic limestone of different degrees of fineness.

While the main advantage of non-acid-forming fertilizers over those that are acid-forming is, in general, the prevention of a harmful increase in soil acidity over a period of years; nevertheless, on sandy soils of relatively low pH value, the beneficial effect may be exerted in part during the first year. This is indicated by the results of Tidmore and Williamson (14)[3] and by the results obtained in an accompanying study by the writers (13). Moreover, it has been shown by Chucka (1), by Knoblauch and Odland (4), and by others that certain soils of the eastern United States are deficient in available magnesium. In order to overcome the deficiency of such soils, fertilizer manufacturers have been adding soluble magnesium salts to fertilizers at a relatively high cost per unit of magnesium oxide. If the magnesium deficiency could be corrected equally well by the substitution of dolomitic limestone, it is obvious that greater economy would result. The making of such a substitution will depend on how much of the magnesium of the dolomitic limestone becomes soluble during the first growing season. It is important, therefore, to compare magnesium sulfate and dolomitic limestone of different degrees of fineness with respect to their effect on the soluble magnesium content of the soil during the first few weeks after the fertilizer is applied.

The question of the relation between degrees of fineness and the rate of decomposition of dolomitic limestone has been studied by MacIntire, *et al.* (6, 7), Morgan and Salter (8), White (18), and others. These investigators have well established the general relation between degrees of fineness and rate of reaction, and also the fact that

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[3]Figures in parenthesis refer to "Literature Cited," p. 773.

dolomitic limestone reacts more slowly in the soil than does calcium limestone, especially with the coarser separates. No studies have been reported, however, where the dolomitic limestone was added as a part of the fertilizer mixture, nor where the amounts of water-soluble magnesium were determined after relatively short intervals of time.

The objectives of this investigation were as follows:

1. To compare the concentrations of soluble magnesium in the soil-fertilizer zone when magnesium sulfate and when dolomitic limestone of different degrees of fineness are used as the sources of magnesium in the fertilizer.
2. To determine the effect of the fineness of dolomitic limestone on its rate of decomposition in the soil-fertilizer zone when used as a constituent of mixed fertilizers.
3. To compare the rate of decomposition of dolomitic limestone obtained from different sources.

METHOD OF STUDY

This investigation was carried out in the greenhouse with a Dekalb silt loam of pH 5.4. All fertilizers used in the study had the composition of 4–10–6. In all cases three-fourths of the nitrogen was derived from ammonium sulfate and one-fourth from ammonium phosphate, the phosphorus partly from ammonium phosphate and partly from superphosphate, and the potash all from muriate of potash. As shown in Table 1, the fertilizers differed only in regard to the amount and kind of dolomitic limestone or of magnesium sulfate used as filler. All dolomitic limestone separates were obtained by wet screening.

After thoroughly mixing the bulk sample of soil and placing 4,000-gram samples in 22 1-gallon pots, the fertilizers were added and thoroughly mixed with the soil. In order to simulate as much as possible the soil-fertilizer zone under row applications in the field (13), the fertilizers were applied at a rate of 12,000 pounds per 2,000,000 pounds of soil. If it is assumed that in hill or row application the fertilizer is mixed with only one-tenth of the surface 6⅔ inches of soil, then the rate given above is comparable to 1,200 pounds per acre. After fertilization the soil was brought to approximately optimum moisture content and distilled water added at regular intervals to compensate for losses by evaporation. All treatments were in duplicate. After various intervals, soil samples were removed for determinations of soluble magnesium, nitrate nitrogen, and pH.

The water extract of the soils was obtained by the dialysis method (12) after the soil had been in contact with the water for 18 hours in the presence of sufficient toluene (1 cc per 125 cc water) to prevent denitrification. The pH was determined by the colorimetric method (12), nitrates by the phenoldisulfonic method, and magnesium by the method described by Kramer and Tisdall (5).

CONCENTRATION OF WATER-SOLUBLE MAGNESIUM IN THE SOIL-FERTILIZER ZONE

In Fig. 1 are shown the increases in water-soluble magnesium in the soil-fertilizer zone obtained when magnesium sulfate and when dolomitic limestone of different degrees of fineness were used as sources of magnesium in the fertilizer applied. Where no magnesium was applied in the fertilizer, the water-soluble magnesium found in

TABLE 1.—*Description of supplements used in fertilizers.*

Fertilizer No.	Magnesium compounds used in fertilizers*			Partial composition of dolomitic limestone	
	Source†	Fineness	Pounds per ton of fertilizer	$CaCO_3$ %	$MgCO_3$ %
1	—	—	—	—	—
2	Dolomitic limestone (B)	20–40 mesh	343		
3	Dolomitic limestone (B)	60–80 mesh	343		
4	Dolomitic limestone (B)	Finer than 100 mesh	343	58.3	41.1
5	Dolomitic limestone (B)	Finer than 100 mesh	228		
6	Dolomitic limestone (B)	Finer than 100 mesh	114		
7	Dolomitic limestone (B)	Mixture of different separates‡	343		
8	Dolomitic limestone (A)	Mixture of different separates‡	345	58.5	42.3
9	Dolomitic limestone (C)	Mixture of different separates‡	383	56.7	36.3
10	Dolomitic limestone (D)	Mixture of different separates‡	348	57.1	41.5
11	$MgSO_4.7H_2O$	—	131	—	—

*In addition to these materials, quartz sand was used in all cases in sufficient amounts to make the analysis 4-10-6.

†The four samples of ground dolomitic limestone were obtained from West Virginia, Ohio, Tennessee, and Alabama.

‡Mechanical analysis: All through 40-mesh sieve; 20% through 40-mesh but held on 60-mesh sieve; 20% through 60-mesh but held on 80-mesh sieve; 10% through 80-mesh but held on 100-mesh sieve; and 50% through 100-mesh sieve.

the soil varied from 28.1 p.p.m. after the 24-day period to 48.4 p.p.m. after 171 days. The increases are shown after 24, 52, 84, and 171 days. The dolomitic limestone "mixture" curve as shown in Fig. 1 represents the average increase obtained from the dolomite mixtures from the four different sources.

As was to be expected, the finer material reacted more quickly than the coarser particles and as the time increased more magnesium was brought into solution. The rate of solution of the finer than 100-mesh dolomitic limestone, the 60 to 80 mesh, and the dolomitic limestone "mixture" was rather rapid up to 84 days, but showed a considerable decrease thereafter. The 20 to 40 mesh curve showed a much slower rate of solution.

It is interesting to observe the similarity of the curves representing pure magnesium sulfate and finer than 100-mesh dolomitic limestone applied at one-third standard rate. The magnesium sulfate was used at a rate sufficient to supply 12.9 pounds of magnesium per ton of fertilizer and the one-third standard rate dolomitic limestone supplied 13.6 pounds. A comparison of these two curves shows that the dolomitic limestone finer than 100-mesh liberated just about as

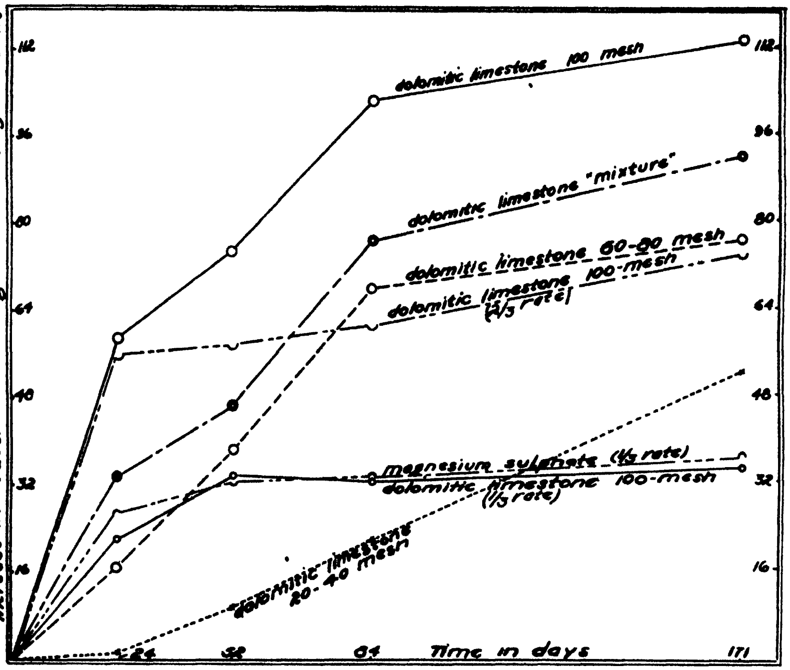

FIG. 1.—The relationship between fineness of dolomitic limestone and concentrations of water-soluble magnesium in the fertilized soil after various intervals of time.

much soluble magnesium per pound of total magnesium added as did pure magnesium sulfate. In comparing the dolomitic limestone "mixture" and magnesium sulfate curves, it is seen that the former supplied slightly more soluble magnesium in the soil-fertilizer zone after 24 days and over twice as much after 84 days. Since about three times as much total magnesium was added in the dolomitic limestone "mixture", however, it is seen that for each unit of magnesium supplied it required, after the 24- and 84-day periods, respectively, 3 and 1½ times as much of the dolomitic limestone "mixture" as of magnesium sulfate to supply the same amount of soluble magnesium.

It should be emphasized, however, that all the nitrogen used in the experiment was from acid-forming sources. With fertilizers containing relatively low percentages of acid-forming sources of nitrogen it is possible that the rate of solubility of dolomitic limestone

would be somewhat less than that found in this experiment. Likewise, the rate of decomposition of limestone of different degrees of fineness would be influenced to some extent by the original acidity of the soil (11).

Table 2 shows the percentage recovery of water-soluble magnesium in the soil-fertilizer zone from the magnesium sulfate and dolomitic limestone treatments after various intervals of time. After 24 days, 69.2% of the magnesium from the magnesium sulfate treatment was recovered in the soil extract, and 85.9, 84.9, and 99.4% recovered after 52, 84, and 171 days, respectively. These figures show, as would be expected, that even though magnesium sulfate is considered as being 100% available to plants, only part of the magnesium added was recovered in the soil extract during the early periods. The remainder was probably present in exchangeable form, and likewise available to plants.

TABLE 2.—*The effect of source of magnesium and of fineness of dolomitic limestone on the soluble magnesium content of the soil after different periods of time.*

Source of magnesium in fertilizer	Pounds magnesium added per ton of fertilizer	Percentage magnesium recovered in soil extract after			
		24 days	52 days	84 days	171 days
Dolomitic limestone, 20–40 mesh	40.7	1.4	8.4	18.1	43.1
Dolomitic limestone, 60–80 mesh	40.7	13.9	31.9	56.2	63.5
Dolomitic limestone, 100 mesh	40.7	48.5	61.5	84.4	94.1
Dolomitic limestone (1/3 standard rate) 100 mesh	13.6	55.6	83.9	80.7	90.3
Dolomitic limestone (2/3 standard rate) 100 mesh	27.2	69.5	76.6	76.4	92.8
Dolomitic limestone, "mixture"*	41.1	27.6	38.1	62.9	75.1
$MgSO_4.7H_2O$	12.9	69.2	85.9	84.9	99.4

*Data represent an average obtained from the four dolomitic limestones of different sources. See Table 1 for chemical and mechanical analyses

Assuming that the increase of soluble magnesium in the soil-fertilizer zone is a measure of decomposition, the comparison between the amounts of magnesium recovered from magnesium sulfate and from the various grades of dolomitic limestone can be used as a basis for determining the decomposition of the latter after various intervals of time. Using the percentage recovery of magnesium from readily soluble magnesium sulfate, given in Table 2, as a standard of 100, the decomposition of the different grades of dolomitic limestone at each date were calculated and are shown in Table 3. It is noted that the finer than 100-mesh dolomitic limestone is only 70% as effective as magnesium sulfate in increasing the soluble magnesium in the soil-fertilizer zone at 24 and 52 days when used at the standard rate, whereas when used at one-third standard rate it was practically as effective, as shown in Fig. 1. This is no doubt due to the fact that the more dolomite added, the longer it takes for all of it to react. The table emphasizes the fact that the coarse material reacted very slowly. After 24 days only 2% of the 20 to 40 mesh and 20% of the

60 to 80 mesh material had reacted, as compared with 70% of the finer than 100-mesh material. At the end of 84 days practically all the finer than 100-mesh dolomitic limestone had reacted as compared with 66% of the 60 to 80 mesh and only 21% of the 20 to 40 mesh. The decomposition at this time is of special interest because it probably represents the maximum that would be available during the first growing season. The dolomitic limestone "mixture" again represents the average results obtained from the dolomitic limestone from the four different sources. The calculated value of the "mixture" was figured from the results obtained from the individual separates as given in Table 3, and as can be seen these results agree well with the results of the dolomitic limestone "mixture" as obtained in the experiment.

TABLE 3.—*The effect of fineness of division of dolomitic limestone on its rate of decomposition in the soil as measured by the accumulation of water-soluble magnesium*

Fineness of dolomitic limestone used in fertilizer	Percentage decomposed based on increase in water-soluble magnesium in the soil after*			
	24 days	52 days	84 days	171 days
Finer than 20 mesh, coarser than 40 mesh	2.0	9.7	21.3	43.3
Finer than 60 mesh, coarser than 80 mesh	20.0	37.1	66.1	63.9
Finer than 100 mesh	70.1	71.5	99.4	94.7
Mixture of separates†	39.8	44.3	74.1	75.6
Mixture of separates, calculated value‡	45.8	53.3	79.9	78.8

*Amount of water-soluble magnesium obtained with magnesium sulfate used as standard of comparison.

†Data represent an average obtained from the four dolomitic limestones of different sources. See Table 1 for chemical and mechanical analyses.

‡Calculated from the result of the individual separates. Values for the 40–60 and 80–100 mesh separates assumed to be intermediate between the 20–40 and the 60–80 mesh separates in the former case and between the 60–80 and 100 mesh separates in the latter.

Morgan and Salter (8), working with three true dolomitic limestones on a Trumbull silt soil of pH 5.6, found that about 19% of the 50-mesh and 52% of the 100-mesh material had decomposed after 35 days. By interpolation in Fig. 1 for 35 days and assuming 50-mesh dolomitic limestone to be intermediate between the 20 to 40 and 60 to 80 mesh and the 100-mesh between the 60 to 80 and finer than 100-mesh, it is found that 12.5% of the 50-mesh and 37.5% of the 100-mesh material had decomposed. These results agree rather well when it is considered that two entirely different methods of determining decomposition were used. Morgan and Salter measured decomposition by determinations of residual carbonates, whereas in this investigation only soluble magnesium was considered.

ACCUMULATION OF NITRATE NITROGEN IN THE SOIL-FERTILIZER ZONE

It is well known that the addition of limestone to an acid soil increases nitrification, and it has been found in an accompanying investigation (13) that the use of non-acid-forming fertilizers materially

affects nitrate accumulation in the soil-fertilizer zone. It seemed desirable, therefore, to study the effect of fineness of division of dolomitic limestone used as a constituent of mixed fertilizers on nitrification of the added ammonia in the soil-fertilizer mixture. Fig. 2 shows the accumulation of nitrate nitrogen in p.p.m. after 24, 52, 84, and 171 days. It is seen that the addition of dolomitic limestone has materially increased nitrification. This is especially noticeable

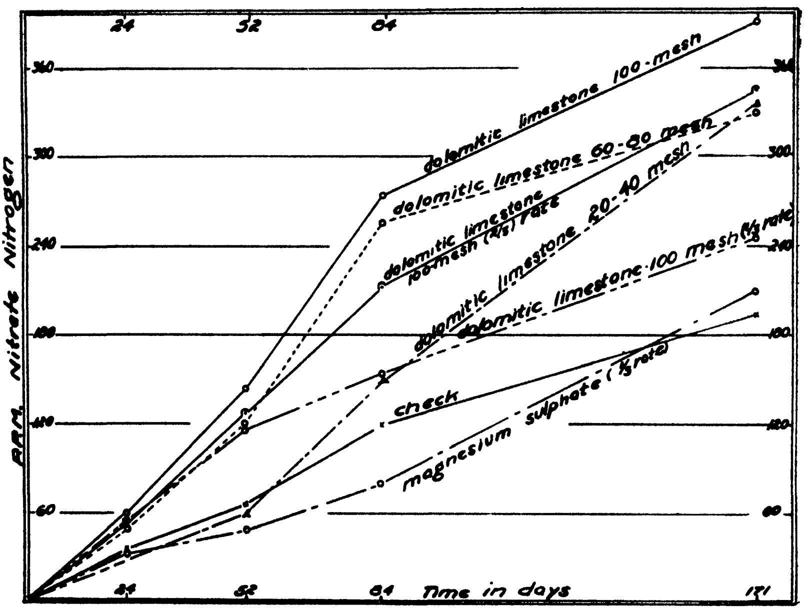

FIG. 2.—Relation between fineness of dolomitic limestone and concentration of nitrate nitrogen in the fertilized soil after various intervals of time.

where the separates were of 60 to 80 mesh or finer. After 24 days the finer than 100-mesh dolomite applied at standard rate in the fertilizer had practically doubled the accumulation of nitrate nitrogen over the check. This increase is maintained throughout the experiment and at the end of 171 days there is still twice as much nitrate nitrogen where finer than 100-mesh dolomitic limestone had been used as where no dolomite had been added. When the finer than 100-mesh separates at one-third, two-thirds, and standard rates are compared, it can be seen that the more dolomitic limestone is added, the greater is the accumulation of nitrate nitrogen. This increase is not so noticeable at 24 days, but as the time increases the differences between the different rates increase. It is interesting to note that the 20 to 40 mesh dolomitic limestone caused no increase in nitrate nitrogen accumulation over the check at either 24 or 52 days, but thereafter nitrification increased until after 171 days the 20 to 40 mesh was as effective as the 60 to 80 mesh material which had over 1½ times the accumulation of nitrate nitrogen as the check.

The increased nitrate accumulation in the soil-fertilizer zone, as a result of the presence of dolomitic limestone in the fertilizer, may under certain conditions be of considerable importance since it has been shown by Tiedjens (16, 17) and others (2, 3, 9) that at low pH values nitrate nitrogen is more readily utilized by plants than is ammonia nitrogen.

COMPARISON OF DOLOMITIC LIMESTONE FROM FOUR WIDELY DIFFERENT SOURCES

In Table 4 is shown a comparison of dolomitic limestones from Alabama, Tennessee, Ohio, and West Virginia in regard to their effect upon the concentration of water-soluble magnesium, nitrate nitrogen, and hydrogen ions of the soil in the fertilized zone. The composition of these dolomitic limestones from various sources varied somewhat in percentage calcium and magnesium, as shown in Table 1, but the total amount of magnesium added to the soil was practically the same in all cases. The mechanical analysis, also given in Table 1, shows that the limestones were all of the same degree of fineness. If, as shown in Table 4, the results with dolomitic limestone A are taken as a standard of 100, it is seen that on the average dolomitic limestone B is 98% as effective in supplying water-soluble magnesium in the soil-fertilizer zone, whereas dolomitic limestones C and D are 108 and 118% as effective, respectively. The relative ranks change from 24 to 52 and from 52 to 84 and also from 84 to 171 days, so it might be said that there is no consistent difference between the different dolomitic limestones. Likewise, the differences in the accumulation of nitrate nitrogen in the soil-fertilizer zone from the use of dolomitic limestones from different sources are not great enough to be considered significant and are no doubt due to experi-

TABLE 4.—*Comparative effects of dolomitic limestone from different sources on the soluble magnesium, nitrate nitrogen, and hydrogen-ion concentration of soil in the fertilized zone.*

Source of dolomitic limestone*	Criteria of availability	Relative effects after†				
		24 days	52 days	85 days	171 days	Average
A	Water-soluble magnesium	100	100	100	100	100
B		96	102	105	91	98
C		94	129	89	120	108
D		114	124	105	129	118
A	Nitrate nitrogen	100	100	100	100	100
B		103	83	94	87	92
C		87	108	90	114	100
D		109	107	105	110	108
A	pH	5.50	5.30	5.08	4.83	—
B		5.49	5.33	5.28	4.83	—
C		5.55	5.33	5.15	4.85	—
D		5.48	5.15	5.10	4.80	—

*The four samples of ground dolomitic limestone were obtained from West Virginia, Ohio, Tennessee, and Alabama. See footnote 3 of Table 1 for mechanical analysis.

†With magnesium and nitrate nitrogen the values obtained with dolomitic limestone A are taken as a standard of 100.

mental error. The relative ranks change from one period to another and the average values over a 171-day period are remarkably close.

The pH values as given in Table 4 seem to vary rather closely with the corresponding accumulation of nitrate nitrogen in the heavily fertilized soil. This is to be expected when one considers the fact that the formation of nitrate nitrogen is an acidifying process. It is interesting to note that at the end of 171 days the dolomitic limestone from the four different sources are equally effective in maintaining the same hydrogen-ion concentration in the soil-fertilizer zone. The pH values are lower after 171 days than at the beginning of the experiment, however, even though the fertilizer was only slightly acid-forming. This is probably due to several factors, namely, increased salt concentration, partial decomposition of added dolomitic limestone, and possibly other factors (13).

SUMMARY

Studies were made in the greenhouse with a Dekalb silt loam soil of pH 5.4 to compare the concentration of soluble magnesium in the soil-fertilizer zone when magnesium sulfate and when dolomitic limestone of different degrees of fineness were used in the fertilizer as sources of magnesium. As measured by the concentration of soluble magnesium in the soil-fertilizer zone, the decomposition of dolomitic limestone of different degrees of fineness when used as a constituent of a mixed fertilizer was determined after 24, 52, 84, and 171 days. The rate of decomposition of four dolomitic limestones obtained from widely different sources was also studied.

The results show that after a period of 24 days the finer than 100-mesh dolomitic limestone, when used as a constituent of a mixed fertilizer, liberated in the soil-fertilizer zone practically as much magnesium as did pure magnesium sulfate containing an equivalent amount of magnesium. After the same period it required over 3 times as much 60 to 80 mesh and 35 times as much 20 to 40 mesh as 100-mesh dolomitic limestone to liberate the same amount of magnesium. However, the values obtained after 84 days, which might be taken as representing the maximum amount of magnesium that would be supplied to the growing crop the first year showed that it required only about 1½ and 5 times as much 60 to 80 and 20 to 40 mesh material, respectively, as of 100-mesh material. After 24 days it required about 3 times as much magnesium in the form of a dolomitic limestone "mixture" to supply as much magnesium in the soil-fertilizer zone as pure magnesium sulfate, but after 84 days only 1½ times as much was required.

As measured by the concentration of soluble magnesium, the finer the division of dolomitic limestone used in the production of non-acid-forming fertilizers, the greater the rate of decomposition in the soil-fertilizer zone. It seems evident from the data obtained in the experiment that if much benefit is to be expected from the use of dolomitic limestone in mixed fertilizers during the year in which it is applied, the material should all pass the 20-mesh sieve and a large part should pass the 60-mesh sieve.

Samples of dolomitic limestones from West Virginia, Ohio, Ten-

nessee, and Alabama were studied and it was found that the rate of decomposition of these dolomitic limestones as indicated by the concentration of magnesium, nitrate nitrogen, and hydrogen-ions in the soil-fertilizer zone was practically the same.

Since it has been shown by Tidmore and Simmons (15) and one of the writers (10) that many mixed fertilizers containing 3 to 4% nitrogen have an equivalent acidity of 200 to 400 pounds $CaCO_3$ per ton, it seems probable that if such fertilizers are made non-acid-forming by the use of finely ground dolomitic limestone, they should supply a large part, if not all, of the magnesium needs of plants, even when grown on magnesium-deficient soils.

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NOTE

A FIELD ASPIRATOR FOR EMASCULATING SWEET CLOVER FLOWERS[1]

THE method described by Kirk[2] for emasculating sweet clover flowers, using the suction developed by water pressure, has been successfully used in a greenhouse at the Fort Hays (Kansas) Branch Experiment Station. This method, however, is unsuited for use in the field where water is not available. To overcome this difficulty and to continue the breeding work in the field, a simple and efficient aspirator was developed in the spring of 1933 which provides the suction without the use of water.

FIG. 1.—The manifold-suction method of emasculating sweet clover flowers.

Following a suggestion offered by R. R. Drake, Associate Agronomist, Bureau of Agricultural Engineering, U. S. Dept. of Agriculture, an air-valve pet cock was inserted in the center of the intake manifold of a Model A Ford. Because it provides full suction from all cylinders, this location on the manifold is commonly used to connect a suction tube for the operation of a wind-shield wiper. One end of a quarter-inch pressure tube was fastened to the pet cock and a hypodermic needle was inserted in the other end of the tube. The

[1]Contribution No. 17, the Fort Hays Branch of the Kansas Agricultural Experiment Station and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating.

[2]KIRK, L. E. Abnormal seed development in sweet clover species crosses—a new technique for emasculating sweet clover flowers. Sci. Agr., 10 : 321–327. 1930.

valve when open and with the engine running at idling speed developed slightly more suction than was obtained from local water pressure. The amount of suction may be regulated by varying the speed of the motor or the size of the opening in the valve.

Lack of uniformity in suction, caused by the motor, was overcome by inserting a 2,000-cc vacuum flask in the tube line between the pet cock and the needle. Like the expansion chamber in an aspirator pump, the flask took up the slack in the alternating suctions of the cylinders, and also provided a settling basin for the pollen. The flask was securely fastened to the fender of the car.

By means of this apparatus rapid and uniform emasculation of the flowers was accomplished in the field. It was possible to drive to within a few yards of any plant selected for emasculation. The method of procedure used in manipulating the flowers was the same as that described by Kirk, except that a hypodermic needle was substituted for a glass tube because the latter breaks easily.

Satisfactory results have been obtained at this station from limited use of this aspirator during 1933 and 1934. C. O. Grandfield, Assistant Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, adopted this method of emasculation and reports satisfactory results from its use in breeding alfalfa at Manhattan, Kansas.—D. A. SAVAGE, *Fort Hays Branch Experiment Station, Hays, Kansas.*

BOOK REVIEWS

SOIL DEFICIENCIES AND PLANT DISEASES

By G. V. Jacks and H. Scherbatoff. Harpenden, England: Imperial Bureau of Soil Science. Technical Communication No. 31. 46 pages. 1934. 2/ .

THIS Communication, which apparently has had very little notice in this country, is described by the editors as entirely non-critical and intended as a guide to the original literature. "The literature of the subject is vast, and the possibility of our having omitted some important papers or points of view cannot be overlooked," they state in a brief preface, and continue, "We have, however, collected together what have seemed to us to be the most relevant facts in the several hundred papers we have scanned. We have included fairly detailed descriptions of symptoms, and trust that these may sometimes be found useful in the diagnosis and treatment of diseases of doubtful origin."

The bibliography contains 367 entries. An unique feature of the publication is a table which precedes the bibliography listing the deficient elements, the main crops affected by deficiencies of each element, and the bibliographical references to papers dealing with each deficiency.

Through arrangements made between the publishers and the Chilean Nitrate Educational Bureau of 120 Broadway, New York City, copies of this Communication may be obtained from the latter as long as a limited supply lasts. (J. D. L.)

AN OUTLINE OF BIOMETRIC ANALYSIS

By Alan E. Treloar. Minneapolis, Minn.: Burgess Publishing Co., 65 pages of text and figs. 1935.

THIS is a combined text and notebook and is designed for "aiding students in grasping the fundamentals of courses in biometric analysis given by the author at the University of Minnesota." Only one side of each sheet is used for the text, the other side being left blank for notes. This publication will be welcomed by many research workers who desire to use biometry, but who either have a weak grasp of fundamentals or who wish to have a condensed text giving the various formulas and methods which frequently are scattered thru numerous publications.

There are few modern works that give such a condensed yet comprehensive account of what might be called Pearsonian biometry. The author has not included the work of R. A. Fisher and others on the analysis of variances and covariances but does give considerable space to the χ^2 criterion as developed by Fisher. The publication is worthy of a place in the library of experimentalists who are or should use biometrical methods in their research problems. (F. Z. H.)

THE BIOCHEMISTRY OF THE LIPIDS

By Henry B. Bull. Minneapolis, Minn.: Burgess Publishing Company. 127 pages, illus. 1935.

OUR rapidly changing ideas of the biochemical rôle of certain chemical compounds make the appearance of any up-to-date treatise most appreciated. This is especially true in the case of the lipids, which have not been dealt with in a comprehensive manner in recent years, except that the subject was touched upon by several articles in recent volumes of the *Annual Review of Biochemistry*. The lipids include the carotenes, vitamines A and D, and many other compounds which have been in the focus of scientific interest in recent years. A critical discussion of the modern developments in this field, therefore, is very desirable.

Although few agronomists will use this volume extensively, it will be of great help to many of them in supplying detailed information on this important group of components of the protoplasm. The book, which is based on Professor Bull's lectures at the University of Minnesota, well fulfills this need. It is unfortunate, however, that as in the case of some other books issued by the same publisher, there is no author and subject index to the volume. This fact curtails its usefulness as a reference book, the great number of references given in the volume making this lack of an index even more regrettable.

Bloor's classification is used in the grouping of the material. The main sections of the volume are entitled "Fatty Acids," "Soaps," "Alcohols," "Hydrocarbons," "Sterols," "Fats and Oils," Phospholipids," and "Glycolipids." The remainder of the volume is taken up by a discussion of "Emulsions" and of the "Physiology of Lipids." The latter deals mostly with animal physiology, but includes a short discussion on the "Lipid Physiology of Green Plants," which will be of interest to botanists and agronomists.

A large number of tables and especially the many graphs, together with a critical discussion of the information available in the literature, make this volume most interesting and useful to the student as well as to the research worker. (Z. I. K.)

AGRONOMIC AFFAIRS

PROGRAM OF THE SOIL BIOLOGY SUB-SECTION

THE program for the meetings of the Soil Biology Sub-Section of the Soils Section of the Society in Chicago in December has been provisionally outlined. The Friday morning session will be introduced by several brief papers on the experiences of those members who attended the Third Commission Sessions of the Third International Congress of Soil Science at Oxford, England. These papers will not conflict with, nor duplicate, those papers given at the Thursday afternoon general session of the Soils Section. During the remainder of the Friday morning session papers will be presented which relate to any field of soil biology other than that taken up in the Friday afternoon session.

The Friday afternoon session will be restricted to the consideration of the root-nodule bacteria and related problems on the inoculation of leguminous crops. A special invitation is extended to members of the Society who are connected with the commercial production of legume inoculation cultures to give short talks on some phase of their work.

No special requests for specific papers will be sent to members, but anyone wishing to present a paper before either session is urged to send a preliminary announcement not later than October 1 to the chairman of the Sub-Section, H. W. Batchelor, Agr. Exp. Station, Wooster, Ohio. This announcement should include the title of the paper, the probable length of time required for its presentation, and a brief statement of its contents.

PROGRAM OF THE CROPS SECTION AT CHICAGO

DR. R. D. LEWIS, Chairman of the Crops Section, announces the last call for papers to be presented at the annual meeting in December. Some suggestions for papers appeared on page 584 of the July number of the JOURNAL. These suggestions were not meant to exclude other worthy topics.

The program of the International Crop Improvement Association meeting in Chicago on December 4 will be printed with the program of the Society.

Titles, time required for presentation, and names of authors, as they are to appear on the program, should be sent to R. D. Lewis, Department of Agronomy, Ohio State University, Columbus, Ohio, by October 1.

TOBACCO FERTILIZER RECOMMENDATIONS FOR 1936

RECOMMENDATIONS for the fertilization of flue-cured, sun-cured, and shipping tobacco grown on average soils in Virginia, North Carolina, South Carolina, and Georgia during 1936 have been formulated by the Tobacco Research Committee composed of C. B. Williams, North Carolina, *Chairman;* T. B. Hutcheson, Virginia, *Secretary;* and H. W. Garner and J. E. McMurtrey of the Bureau of Plant Industry; E. M. Matthews, Virginia; H. P. Cooper, W. M. Lunn, and H. A. McGee, South Carolina; E. Y. Floyd, R. F. Poole.

L. G. Willis, and E. G. Moss, North Carolina; and E. C. Westbrook and J. M. Carr, Georgia.

Space will not permit a detailed publication of the recommendations of this Committee in the JOURNAL. The recommendations are available in mimeographed form, however, and may be obtained from the Chairman or the Secretary of the Committee.

DOCTOR CURTIS F. MARBUT

DR. C. F. Marbut, Director of the Soil Survey of the U. S. Dept. of Agriculture since 1910 and an international figure in the field of soil science, died of pneumonia in Harbin, Manchuria, on August 25 while enroute from the International Soil Congress in Oxford, England, to Peiping, China, where he was to undertake a study of the soils of China at the request of the Chinese government.

In addition to supervising the work of the Soil Survey of the U. S. Dept. of Agriculture which has mapped approximately 1,000,000,000 acres of land, or about half of the agricultural area of the United States, Dr. Marbut had also examined and classified the soils of every country of western Europe, except Spain. He was also familiar with the soils of Russia, had directed the classification of the soils of Africa, and had made a study of the soils of South America.

Dr. Marbut had but recently completed an inventory of the soil resources of the entire Nation soon to be published by the Department of Agriculture as part 3 of the *Atlas of American Agriculture*.

A more complete biographical sketch of Dr. Marbut's life and an appreciation of his work will appear in a later number of this JOURNAL.

NEWS ITEMS

DR. CHARLES E. KELLOGG has been named Principal Soil Scientist and Chief of the Soil Survey Division of the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, to fill the vacancy occasioned by the death of Dr. C. F. Marbut.

J. D. TINSLEY of Amarillo, Texas, died on August 5.

THE NINTH ANNUAL alfalfa seed conference of the Western Regional Section of the International Crop Improvement Association was held this year at the College of Agriculture, Madison, Wisconsin, on July 26 and 27. This is the first time that the representatives of the western alfalfa seed growers and seed certifying agencies have held their meeting in the middle west, thus affording a splendid opportunity for 75 producers, consumers, and distributers to discuss the many perplexing problems of the seed industry.

DR. LEROY POWERS resigned July 1, 1935, as Associate Professor of Agronomy and Plant Genetics, University of Minnesota, to accept a position as Geneticist with the Office of Horticultural Crops and Diseases, U. S. Dept. of Agriculture, with headquarters at Cheyenne, Wyoming.

DR. F. R. IMMER resigned as Associate Geneticist, Division of Sugar Plants, U. S. Dept. of Agriculture, on August 1, 1935, to become Associate Professor of Agronomy and Plant Genetics, University of Minnesota. Dr. Immer will devote half time to the Experiment Station as Statistical Adviser to members of the staff.

CARL BORGESON has been appointed instructor in Agronomy and Plant Genetics, University of Minnesota, and will take over the work of seed certification formerly cared for by A. D. Haedecke, who retired on July 1.

WILL M. MYERS was appointed Instructor in Agronomy and Plant Genetics, University of Minnesota, and will have charge of the cytological laboratory of the Division.

S. P. SWENSON, W. W. BROOKINS, and KARL MANKE have accepted research assistantships in the Division of Agronomy and Plant Genetics, University of Minnesota.

ACCORDING to a recent note in *Science*, J. M. Westgate, Director of the Hawaii Agricultural Experiment Station since 1915, has resigned to become professor of tropical agriculture in the University of Hawaii. He is to be succeeded by Dr. O. C. Magistad, formerly chemist for the Pineapple Experiment Station.

Science also reports that R. L. Pendleton, professor of soil technology and head of the Department of Soils, College of Agriculture, University of the Philippines, at Los Banos, has retired to accept a position as soil technologist and agriculturist to the Department of Agriculture of the Siamese Government, with headquarters in Bangkok, Siam.

DR. D. F. JONES, head of the Department of Genetics, Connecticut Agricultural Experiment Station, has been granted leave of absence beginning September 1, for work at the California Institute of Technology at Pasadena.

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WHAT IS A WEED?[1]

A. J. PIETERS[2]

AT the present time a great deal of interest centers in weeds, especially in the control of some of the most obnoxious ones. The question arises, therefore, what is a weed? Perhaps the question is more or less academic, since so far as the serious weeds are concerned at least, there is no dispute as to what they are and that they are serious weeds.

Agronomists should, however, be able to define their concepts as comprehensively and accurately as possible and hence it may not be out of place to renew the inquiry as to the proper definition of a weed. Is it possible to frame a definition at once inclusive and exclusive? The brief discussion herewith covers an attempt to analyze the definitions current or proposed; to point out in what particular they are unsatisfactory and to raise the question whether a better definition can be framed.

The late Dr. Beal, of blessed memory, was the one who offered the definition which has been pretty generally accepted. He said a weed was a plant out of place. While this definition has a great deal to recommend it, it has always seemed to the writer somewhat unsatisfactory. The term "weed" is an odious one and carries with it inevitably the idea of something evil, of something that does harm and should be destroyed. Dr. Beal's definition makes the matter depend on where the plant is found and according to that definition the same plant might at one time be a weed and at another, not a weed. Buckhorn, thistle, and crabgrass would, under this definition, be weeds when found in cultivated fields but when growing along the roadside or in waste places, they would not be weeds. On the other hand, red clover in a garden would be a weed. Except as a concept of the human mind no wild plant is out of place. It is merely a part of the general scheme of nature.

Dr. Beal's definition depends on the place where a plant is found, not upon any character inherent in the plant.

The writer has been very much interested in speculating on this point because in his own garden white clover, bluegrass, and the American elm make more trouble than any other plants. In this

[1]Contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, Washington, D. C. Received for publication August 19, 1935.

[2]Principal Agronomist in charge.

garden are two large elm trees which bloom abundantly every spring and in a few weeks after blooming the lawn and the garden are covered with young elm seedlings. These are certainly out of place, and in the hardy herbaceous border they make a great deal of trouble because each seedling must be picked out individually from between the clumps of hardy perennials. Still, the American elm is certainly not a weed.

It is so with white clover and bluegrass. The more the garden is fertilized the more white clover and bluegrass creep in among the hardy perennials, and it is a constant fight to keep these invaders subdued. At the same time, it is doubtful whether any agronomist would commonly think of these plants as weeds, in spite of the fact that they are decidedly out of place in the hardy border and cause the gardener a great deal of trouble.

Webster defines a weed as "any plant growing in cultivated ground to the injury of the crop or desired vegetation or to the disfigurement of the place; an unsightly, useless or injurious plant." The great majority of plant species are useless to man, most are unsightly at some stage, and there are injurious plants, as some poisonous ones, that never invade cultivated fields. In the corn belt, and elsewhere in the humid East, Kentucky bluegrass grows among alfalfa to the detriment of that crop and if this is called a weed, we are back to Beal's definition and then a plant may be a weed one place and not in another.

The Oxford dictionary says that a weed is "a herbaceous plant not valued for use or beauty, growing wild and rank, and regarded as cumbering the ground or hindering the growth of superior vegetation." Under this definition, would Johnson grass be a weed? It certainly is valued as a hay plant, but it is equally true that under some circumstances it hinders the growth of superior vegetation.

Bailey in his *Cyclopeadia of Horticulture* frankly states that a plant may be a weed in one place and not in another, and continues: "There are of course, species that are habitual weeds; but in their wild state where they do not intrude on cultivated areas, they can scarcely be called weeds." It is clear that Dr. Bailey does not think it possible to define a weed except in terms of location.

In U. S. Dept. of Agriculture Farmers' Bulletin 660 (1915), entitled "Weeds: How to Control Them," by H. R. Cox, the definition of a weed suggested by J. Sidney Cates, is "a wild plant that has the habit of intruding where not wanted." This definition carries the same thought as that expressed by Dr. Beal but goes further and attributes a "habit of intruding" to the plant. But here, too, it may be noted that Kentucky bluegrass has, in the corn belt, the habit of intruding on alfalfa fields.

None of the definitions so far considered get away from the thought that a plant may be a weed or not a weed, depending on where it is. According to these definitions valuable plants like white clover or Kentucky bluegrass may be called weeds, while buckhorn, Canada thistle, and others growing in waste places would not be weeds.

The underlying thought in the use of the word "weed" by the people for more than a thousand years has been that of an undesir-

able plant; not one unwanted here or there, but one fundamentally bad. Such a plant as a thistle was a weed. Such a plant as white clover, well known hundreds of years ago was not called a weed and, of course, Kentucky bluegrass and Johnson grass were not known. Established usage is the foundation of usage in the English language, but new plants not known to the English of the 10th and 11th centuries and new agricultural practices may make it necessary to broaden our concept of what a weed is.

The Forest Service classes all plants on the range as "grasses," "grass-like plants," "trees and shrubs," and "weeds," the latter term covering all other herbs. This is obviously a definition of convenience and without any bearing on the usefulness of the species. It would be better usage to substitute "forbs" for weeds.

Is it possible to get away from this anomalous situation and make a definition that will exclude from the opprobrious term "weed," plants that sometimes grow where they are not wanted? Perhaps this is not possible but the writer would like to have agronomists consider this question anew and as a contribution to the discussion suggests that "a weed is a plant whose potentialities for harm are greater than its potentialities for good." According to this definition, white clover would not be a weed even though it is annoying at times, because its extreme usefulness far outweighs the little harm it does. On the other hand, the Canada thistle would always be a weed no matter where it was because it does a great deal of harm and no good. There will, of course, be some plants as Johnson grass in the South on which there might be a dispute. While Johnson grass is an unmitigated nuisance in cultivated fields, it does provide quite a bit of grazing and in some parts of the South it provides some hay. It is quite certain, however, that farmers would gladly dispense with Johnson grass for hay if there were any way to destroy it utterly; it does more harm than good.

The writer realizes that the application of the definition offered depends on our knowledge of a given plant. This may be incomplete, but so soon as the characteristics of a plant become well known it should be possible to place it in its proper classification, and a weed would be a weed even though temporarily useful to man; a plant like white clover would never be called a weed though it might be temporarily annoying.

Attention is called once more to the fact that in long established usage the term "weed" did not mean "a plant out of place" but meant an injurious plant with no good in it. The term "a plant out of place" is a catchy one but does not conform to ancient usage and permits the inclusion of useful plants among weeds because the useful plants sometimes grow where not wanted.

Possibly a modification of the definition in Farmers' Bulletin 660 might meet the case and we might define a weed as "a plant that does more harm than good and has the habit of intruding where not wanted."

SEED PRODUCTION STUDIES WITH LEGUMES IN HAWAII[1]

C. P. Wilsie[2]

WHILE the use of legumes for green manuring and forage has received a great deal of attention both in the temperate zones and in the tropics, little information is available on the seed production possibilities of many of the species that show promise in tropical and sub-tropical agriculture. Seed production becomes important whenever extensive acreages are planted and particularly when a new variety or species is disseminated to farmers and planters.

LITERATURE CITED

In a study of the agronomic possibilities of the velvet bean (*Stizolobium deeringianum*) in Florida, Scott (4)[3] obtained seed yields of from 20 to 48 bushels per acre using different varieties. A perfect stand seemed to be the most important factor in the determination of yield due particularly to the spreading nature of the plants.

Kennedy and Madson (2) reported on seed production experiments with the mat or moth bean (*Phaseolus aconitifolius*) in California. In a spacing experiment at Kearney Park yields of from 1,557 to 2,614 pounds per acre were obtained. At the University Farm, Davis, yields averaged 715 pounds per acre. This species is an important food crop in India but has never gained much favor in the United States.

Seed yields of several Crotalaria species have been reported by McKee (3). At McNeill, Mississippi, in 1927, *Crotalaria spectabilis* yielded at the rate of 890 to 992 pounds per acre. At Gainesville, Florida, seed yields were much lower for four Crotalaria species, ranging from 16.5 to 657 pounds per acre. Timson (6) stated that sunn hemp (*Crotalaria juncea*) at the Salisbury Experiment Station usually yields from 400 to 800 pounds of seed per acre. The yields are uncertain due to the presence of a Vermicularia blight which sometimes severely attacks the crop. No data are given on the effect of spacing, but for seed production sunn hemp is usually planted in rows 15 to 20 inches apart using about 20 pounds of seed per acre.

Shaw and Khan (5) have reported seed production tests with the pigeon pea (*Cajanus indicus*) and the gram (*Cicer arietinum*). Pigeon pea yields usually range from 600 to 1,800 pounds per acre and the yields of various gram types range from 400 to 1,000 pounds per acre.

In considering alfalfa (*Medicago sativa*), there is a great deal of uncertainty and variability in seed production. Hughes and Henson (1), in generalizing on seed yields in the United States, say that in the corn belt the yields run from 2 to 3 bushels per acre and in the arid west 4 to 6 bushels per acre are common.

EXPERIMENTAL METHODS

In recent years a large number of legumes have been introduced to Hawaii by the Hawaii Agricultural Experiment Station and other local research agencies.

[1]Contribution from the Hawaii Agricultural Experiment Station, University of Hawaii, Honolulu, T. H. Received for publication August 15, 1935.
[2]Agronomist. The author is indebted to Makoto Takahashi, Frank Mercado, and H. F. Willey for assistance in the collection of the field data.
[3]Figures in parenthesis refer to "Literature Cited," p. 790.

Several of these are promising for green manuring and some are desirable for forage. During 1930 to 1933 the seed production possibilities of these species were studied in carefully spaced plantings. Uniform row spacings of 5 feet were used, the object being to insure plenty of space for plant development with little competitive effect from adjacent rows. Within the row three spacings were used, plants being 6, 12, and 24 inches apart, respectively. All plantings were made early in the spring (February 8 to 15) and notes were taken on germination, growth habits, flowering, and seed setting. Seed was harvested whenever ripe and in some species with uneven maturity of pods, several successive harvests were made until the whole crop was finished for that season.

Among the legumes studied some matured seed in about 3 months while others required nearly a year to complete their growth cycle. The yields as obtained in this experiment are based on the production of 10 plants at each spacing. In most cases individual plant yields were recorded, but due to the detail involved only yields per acre will be given. The experiments were carried on during two successive years, 1930 and 1931, and average yields for the two years are given in Table 1.

While the data would undoubtedly be more reliable had the plats been laid out with a number ot replications and still closer spacings used, it is believed that the results obtained are worthy of publication because of the accuracy of the space planting and individual plant harvesting methods used. The plats were located at the Pensacola Street Station in Honolulu at an elevation of about 85 feet above sea level. The average rainfall in that vicinity is 30 to 35 inches per year.

RESULTS

The results given in Table 1 indicate excellent possibilities for seed production with most of the species tested. The closest spacing used (6 inches) gave the highest yield in most cases. In some instances still higher yields would probably have been obtained with a closer spacing of plants than was used in this experiment. It is fortunate that among those species which offer greatest promise as green manuring crops, *Crotalaria juncea*, *Crotalaria anagyroides*, and velvet beans, all have favorable seeding habits under Honolulu conditions.

SEED YIELDS OF THE BLUE LUPINE

At an elevation of 2,100 feet at the Haleakala Substation on the island of Maui a detailed spacing experiment was conducted with the blue lupine (*Lupinus augustifolius*). Of the many legumes tested at this elevation, the blue lupine has proved to be the most successful for green manuring. Rows were planted 5 feet apart with hills spaced 6, 12, 24, 36, and 48 inches in the row. The number of plants per hill was also varied from one to five thus giving a comparison of 25 different types of spacing. The seed yields obtained are recorded in Table 2. The effect of spacing upon the yield per plant and upon the yield per acre is given.

As the number of plants per acre increased, the yield per plant decreased. This seems to be generally true in all of the five planting groups differing in number of plants per hill. In yields per acre there seems to be a direct positive correlation between the number of plants per acre and total acre yield. This relation would hold only for a

TABLE 1.—*Seed yields of legumes, two years' results.*

Species	Accession No.	Months to mature	Spacing of plants within the row (rows 5 feet apart), in.	Yield per acre, lbs.
Crotalaria usaramoensis	2303	7	6 12 24	915 1,154 816
Crotalaria spectabilis	2301	5	6 12 24	1,050 782 560
Crotalaria juncea (sunn hemp)	2296	5–6	6 12 24	938 1,074 596
Crotalaria anagyroides	2293	9	6 12 24	1,102 784 510
Crotalaria grantiana	2305	8	6 12 24	2,830 1,950 1,586
Phaseolus mungo (urd bean)	2309	4	6 12 24	1,136 991 632
Phaseolus lathyroides (wild pea bean)	2311	4	6 12 24	493 264 123
Cicer arietinum (gram)	2319	4	6 12 24	403 381 254
Phaseolus aconitifolius (moth bean)	2315	3-4	6 12 24	934 730 393
Cassia occidentale	2324	8	6 12 24	5,794 2,657 2,853
Canavalia ensiformis (jack bean)	2328	7	6 12 24	3,528 3,071 2,146
Stizolobium deeringianum (velvet bean)	2333	7	6 12 24	2,439 2,004 1,797
Stizolobium deeringianum (velvet bean)	2334	7–8	6 12 24	3,136 2,526 1,971

TABLE 1.—*Continued.*

Species	Accession No.	Months to mature	Spacing of plants within the row (rows 5 feet apart), in.	Yield per acre, lbs.
Melilotus alba annua (hubam)	2337	6–7	6 12 24	1,699 1,612 1,345
Desmodium uncinatum (Spanish clover)	2340	4–5	6 12 24	518 394 282
Medicago sativa (Chilean alfalfa)	2341	5	6 12 24	722 698 650
Medicago sativa (hairy Peruvian alfalfa)	2342	5	6 12 24	864 738 556
Teprosia candida	2345	13	6 12 24	1,090 1,046 458
Tephrosia noctiflora	2346	8	6 12 24	3,245 3,006 1,802
Leucaena glauca (ekoa)	2348	10	6 12 24	5,488 3,006 2,146
Phaseolus calcaratus (rice bean)	2354	3	6 12 24	328 202 132

certain series of values, beyond which further increases in plants per acre would result in a decrease in yields.

SPACING EXPERIMENTS WITH PIGEON PEAS

The effect of spacing on the yield of "Strain D" variety of pigeon peas (*Caianus indicus*) was studied at the University Farm, Honolulu. This variety has proved to be extremely valuable for forage, green manuring, and, to some extent, human food and is widely scattered at low and medium elevations in various parts of the territory. Using a row spacing of 5 feet, hills were spaced 2½ feet, 5 feet, and 7½ feet, respectively. The number of plants per hill varied from one to four. Two crops of seed were harvested from these plats and the total yields given in Table 3. There were four replications of plats in this experiment.

TABLE 2 —*Effect of spacing on seed yield of blue lupine (L. angustifolius).*

Spacing of hills within the row (rows 5 feet apart), in	Plants per acre	Yield per plant, ozs.	Yield per acre, lbs.
	1 Plant per Hill		
6	17,424	1 59	1,738
12	8,712	2 77	1,511
24	4,356	3 98	1,085
36	2,904	4 33	786
48	2,178	3 64	496
	2 Plants per Hill		
6	34,848	0 84	1,837
12	17,424	1 11	1,211
24	8,712	1 99	1 086
36	5,808	2 05	744
48	4,356	1 85	505
	3 Plants per Hill		
6	52,272	0 66	2,154
12	26,136	1 00	1,644
24	13,068	1 67	1,367
36	8 712	2 03	1,110
48	6,534	1 56	637
	4 Plants per Hill		
6	69 696	0 42	1,846
12	34,848	0 73	1,600
24	17,424	1 23	1,342
36	11 616	1 54	1,118
48	8,712	1 28	698
	5 Plants per Hill		
6	87 120	0 47	2 559
12	43,560	0 59	1,606
24	21 780	0 96	1,308
36	14 520	1 14	1,077
48	10,890	1 33	909

TABLE 3 —*Effect of spacing on yield in the pigeon pea (Cajanus indicus)*

Spacing of hills, ft	No of plants per hill	No of plants per acre	Yield per acre in two crops, lbs	Mean yield per acre for each spacing series, lbs
5 x 2½	1	3,485	4,016±10%*	
	2	6,970	3,406	
	3	10,455	3,697	3,777±189*
	4	13,940	3,988	
5 x 5	1	1,742	3,611	
	2	3,485	3,740	
	3	5,227	3,304	3,724±186
	4	6,970	4,243	
5 x 7½	1	1,162	3,941	
	2	2,323	3,817	
	3	3,485	4,432	4,195±210
	4	4,646	4,589	

*Standard error

The results indicate that spacing 5 x 7½ feet is slightly the best, though statistical analysis shows this difference to be insignificant. There is also very little difference in yield whether there are one or four plants per hill. The growth habit of the pigeon pea is such that it readily adapts itself to the space available (Fig. 1). This seems to be true within rather wide limits of spacing for there are more than 10 times as many plants per acre with four plants per hill at the 5 x 2½ foot spacing as there are with one plant per hill at the 5 x 7½ foot spacing; yet the yields are nearly the same.

FIG. 1.—A single plant of pigeon pea (*Cajanus indicus* Spreng.), showing profuse branching when allowed adequate space for development.

When still wider spacings are used, the yield gradually falls off as may be shown in Table 4. This experiment was laid out in a different field, lower in fertility, and one crop only was harvested. Yields, therefore, should be at least doubled to compare with those in Table 3.

For seed production purposes under conditions similar to those which obtained in these experiments the use of more than 4,000 to 5,000 plants per acre is probably not justified. Under less favorable conditions, when the plant growth is much smaller, a higher rate of seeding would be more desirable.

SUMMARY

Seed yields are reported for a number of green manuring and forage legumes grown at different spacings under Hawaiian conditions. The possibilities for seed production are very favorable for most of the legumes tested. A fairly close spacing of plants gave better results with most species than a wide spacing.

A detailed spacing experiment with the blue lupine grown at 2,100 feet elevation is reported. With the blue lupine the hill spacing of 6 inches was better than any wider spacing. This held true regardless of the number of plants per hill. The use of three, four, or five plants per hill (considering each spacing series) gave slightly higher yields than one or two plants per hill. Increases in yield resulted from an increase in the number of plants per acre until about 87,000 plants were used.

Seed production with the pigeon pea was studied at low elevations in Honolulu. It was found that within rather wide limits a change in spacing had but little effect on yield. This species seems to possess the remarkable ability to utilize the space offered. If planted thick-

ly the stems were slender and grew straight up with little branching, while if given adequate space the plants became very bushy with a great deal of branching. This adaptability resulted in yields that were approximately the same when the number of plants per acre was varied from 2,000 to 14,000.

TABLE 4.—*Pigeon pea yields under widely differing spacings but with only one plant per hill.*

Spacing, ft	Plants per acre	Yield per acre (one crop only), lbs.
5 x 1	8,712	1,732
5 x 2	4,356	1,509
5 x 3	2,904	1,297
5 x 4	2,178	1,200
5 x 5	1,742	1,067
7½ x 1	5,808	1,142
7½ x 2	2,904	1,168
7½ x 3	1,936	845
7½ x 4	1,452	876
7½ x 5	1,162	770
10 x 2½	1,742	784
10 x 5	871	785
10 x 7½	581	655
10 x 10	436	512

Differences in the fertility level, soil moisture, and seasonal conditions undoubtedly have a great influence on the yield of seed under different spacing treatments It is not presumed that the data presented give precisely the best spacing to use with each of the legumes considered. It is believed, however, that the results do present a reasonably satisfactory basis for the adoption of spacing recommendations when grown under conditions similar to those found in Hawaii.

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THE RHIZOMES OF CERTAIN SPECIES OF GRASSES[1]

MORGAN W. EVANS AND J. E. ELY[2]

ACCORDING to the earlier use of the term, *rhizome* meant the procumbent rooting stems of any plant, whether they grow on or beneath the surface of the soil (4, p. 882).[3] According to the most recent usage, which is adopted in this discussion of grasses, the term rhizome refers only to rooting stems which grow beneath the surface of the soil, although in some cases they may originate just above the surface. Rooting stems growing above the surface of the soil are called *stolons*.

All rhizomes have certain common characteristics. The investigations here described, however, show that the rhizomes of grass species also differ in respect to their habits of growth.

In four of the five species studied, i. e., Canada bluegrass (*Poa compressa L.*), quackgrass (*Agropyron repens L.*) (Beau.) redtop (*Agrostis alba L.*), and reed canary grass (*Phalaris arundinacea L.*), the rhizomes originate almost entirely below the surface of the soil from buds at the nodes of other rhizomes. On the other hand, plants of Kentucky bluegrass (*Poa pratensis L.*) very commonly, though not always, produce rhizomes from buds in the axils of fully developed leaves on above-ground shoots. Usually, these buds are just below the surface of the soil, but not infrequently they grow from buds slightly above it. Although a rhizome of Kentucky bluegrass may originate from a bud just above the surface of the soil, it soon turns downward and completes its development below the surface.

In 1932 and in 1933 during the first part of each month from spring until fall, examinations were made of plants of the five species of grasses previously mentioned for the purpose of obtaining records of the development of the rhizomes. The plants were all taken from cultivated row plats 4.0 x 3.3 feet apart to which they had been transplanted on May 18, 1931. The culms of these plants were not cut during the entire season. Each month the soil was washed away from two or three plants, usually the latter number, of each species and records made of the number and length of the rhizomes, and of the number of internodes of which each was composed.

Since the plants were continually increasing in size, by the late spring of 1933 they had become so large that more time was required for making records of whole plants than was available. Accordingly, from May 1933 until the final records were made in the fall of that year, each plant was divided, as accurately as possible, and records

[1]Contribution from the Timothy Breeding Station, North Ridgeville, Ohio, conducted cooperatively by the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication July 19, 1935.

[2]Associate Agronomist and Agent, respectively, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[3]Figures in parenthesis refer to "Literature Cited," p. 797.

made from either half or quarter plants. The records for the whole plant were then derived from the data obtained from the fractional part.

TIME RHIZOMES DEVELOP

Table 1 shows that the number of rhizomes developed is not the same at different times of the year. At certain seasons they form in greater numbers than at other times, as there are certain seasons when different phases of development of above-ground shoots occur. These periods of development vary to some extent for different species.

TABLE 1.—*Average number of new rhizomes per plant having either one or two internodes each in different months in 1932 and 1933 on plants of different species, transplanted on May 18, 1931.*

Month	Canada bluegrass	Kentucky bluegrass	Quack-grass	Red-top	Reed canary-grass
			1932		
June....	9.0	15.5	25.0	1.5	21.0
July....	4.3	18.3	8.6	28.6	9.0
Aug. ...	44.3	3.3	2.0	1.3	6.6
Sept....	8.6	0.3	1.3	7.0	2.0
Oct.....	19.6	2.3	2.3	7.6	1.3
Nov.....	29.0	3.0	1.3	4.6	0.6
			1933		
Apr.....	0.3	0.0	0.7	0.0	0.0
May....	3.3	0.3	38.0	0.3	7.3
June....	2.7	5.3	16.0	3.3	11.0
July....	0.3	2.0	5.0	3.0	4.5
Aug.....	218.7	21.0	49.7	8.7	6.0
Sept....	187.5	6.0	16.5	2.0	2.0
Oct.....	13.0	0.5	20.5	1.0	2.0

The numbers of rhizomes which developed during different months may have been affected to some extent by the amount of precipitation. In 1933, especially during the late spring and summer, there was a marked deficiency in the rainfall. Table 2 shows the monthly and the annual rainfall in 1932 and in 1933, and also the mean for the years 1871 to 1934, at the U. S. Weather Bureau Station at Cleveland, Ohio, which is located approximately 20 miles from and is at about the same altitude as the Timothy Breeding Station at North Ridgeville, Ohio, where these studies were made.

TABLE 2.—*Monthly and annual precipitation in 1932 and 1933, and the mean for the years 1871 to 1934, in inches, at the U. S. Weather Bureau Station, Cleveland, Ohio.*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1932....	3.46	1.10	3.39	2.09	3.71	1.88	2.42	4.31	1.45	3.06	2.63	3.77	33.27
1933 ...	1.40	1.99	3.51	2.42	2.86	0.39	1.26	1.98	2 73	0.97	3.06	1.60	24.17
Mean, 1871-1934	2.59	2.43	2.76	2.48	3.06	3.26	3.55	2.86	3.26	2.78	2.60	2.39	34.02

RELATIVE TIME OF DEVELOPMENT OF NEW RHIZOMES AND OF NEW ABOVE-GROUND SHOOTS

The data in Table 1 show that, generally, new rhizomes are developing in the greatest numbers during June, July, August, and early September. Conversely, above-ground shoots develop in relatively small numbers during the midsummer months. In the latitude of northern Ohio, they appear in the greatest numbers from about August until the close of the growing season, and continue to develop during April and early May in the following season. As the numbers of new rhizomes again increase after this time, there is a decrease in the numbers of new above-ground shoots. Although the seasons for the greatest numerical development of rhizomes and of above-ground shoots overlap to some extent, they do not coincide.

DURATION OF TIME RHIZOMES CONTINUE GROWTH

During the period from June 2 to 13, 1932, a large number of young rhizomes on plants of different species of grass, each rhizome having from one to four elongated internodes, were marked with copper wire and the soil replaced over them. Later, an examination was made of 10 of these marked rhizomes of each species distributed on several different plants on each one of two dates, July 12 to 13, and again on August 9.

The records show considerable variation in the duration of growth of rhizomes of different species. On August 9, rhizomes on plants of Canada bluegrass and reed canarygrass, which had begun their growth in late May or early June, had all terminated as above-ground shoots. On the plants of quackgrass, all excepting 1 of the 20 rhizomes examined in July and August were continuing their growth up to that time as rhizomes. About one-half or a little more of the rhizomes of Kentucky bluegrass and of redtop first observed in June had terminated as above-ground shoots during July and August.

Rhizomes which began their development in late summer or fall continued growth for a longer time. Examinations made at the beginning of the growing season early in the spring of plants of all species have shown large numbers of rhizomes which began their growth in the preceding year. During the spring, the tips of many of the branches which had hitherto grown as rhizomes became transformed into above-ground shoots.

MODES OF BRANCHING

The variety of forms of rhizome systems of grasses may be compared with the great variety of forms of their inflorescences. The differences in the rhizome systems, like the differences in the inflorescences, is due very largely to variations in the manner of branching.

Three types of branching of rhizomes occurring in grasses are represented among the species used in this study.

The type of rhizome development illustrated by Canada bluegrass is comparatively simple. Rhizome branches grow from nodes on the

rhizomes producing them, often at fairly regular distances apart. This process continues until the terminal bud of the older rhizome finally develops into an above-ground shoot. By this time new branches may be growing from the first set of rhizome branches.

In general, the branching systems of the rhizomes of quackgrass (5) and of redtop resemble that of Canada bluegrass. In respect to details, however, such as the length and diameter of the rhizomes, length of the internodes, and the frequency at which new branches develop, there is quite wide variation among the plants of these species.

The growing habits of the plants of Canada bluegrass and of Kentucky bluegrass differ in various ways (3). One of these differences is the manner in which the rhizomes originate.

As stated, new rhizomes on plants of Canada bluegrass usually grow from buds at nodes on other rhizomes beneath the surface of the soil. Although some of the branches develop on plants of Kentucky bluegrass in the way described for Canada bluegrass, a large proportion of the new rhizomes develop from nodes between non-elongated internodes at the base of the above-ground shoots. The number of branch rhizomes growing directly from the base of a single shoot does not often exceed two or three and may be less. From other buds in the axils of leaves at the base of the terminal above-ground shoot, however, new lateral above-ground shoots grow, and from these secondary shoots still other newer branches may develop, all of which forms a more or less dense tuft of above-ground stems.

Not infrequently, on a rhizome of Kentucky bluegrass the internodes near its tip may fail to become elongated. From several of the nodes connected by these non-elongated internodes, branch rhizomes may grow in the form of a tuft below the surface of the soil in a way somewhat similar to that in which a tuft of above-ground stems develop.

The third, somewhat different, type of systems of rhizomes may be illustrated by those of reed canarygrass. In the plants of this species each rhizome grows for a time from the bud from which it originated, then, as in other species, the terminal bud grows upward toward the surface of the soil and produces an above-ground shoot. A new rhizome develops and grows, very commonly in the same direction as the original one, from a bud near the tip of the older rhizome or from one in the axil of a leaf at the base of the above-ground shoot which develops from it. The second one may also terminate in an above-ground shoot, and a third rhizome develop and grow in the same general direction as the older ones. Successive rhizomes may then develop in this way. Although very frequently only one branch rhizome develops near the tip of an older one, yet sometimes several form, and the direction of growth of some or even of all of them may be different from that of the parent rhizome.

RATE AT WHICH PLANTS SPREAD BY MEANS OF RHIZOMES

The area over which a grass plant spreads within a given length of time depends upon a number of factors (2, p. 8). Some of these conditions are soil and climate or weather; others are inherent in the

plants themselves, such as the lengths to which the rhizomes grow and the frequency at which new branch rhizomes appear.

The rates at which different plants of the same species spread outward over the adjoining area also may differ greatly (1).

The average area occupied by three plants, of each of several species of grass examined from April 17 to May 9, 1932, as measured by the minimum and the maximum diameters, is shown in Table 3. This table gives information as to the lengths of the rhizomes, the lengths and numbers of the internodes of which they are composed, and the percentage of nodes from which branches had developed.

At the time of transplanting on May 18, 1931, each plant consisted of a single original rhizome having several elongated internodes and terminated in an above-ground shoot. The new rhizomes developing from the original may be referred to as the primary branches and the rhizomes originating from the primary branches as the secondary ones. The rhizomes described represent these secondary branches, as shown in Table 4.

TABLE 3.—*Growth made up to April 17 to May 9, 1932, by plants from single rhizomes which had been planted May 18, 1931.*

Species	Average maximum and minimum diameter of plant, inches	Length in inches per			Average number per rhizome of elongated internodes	Percentage of elongated internodes with branch at distal node
		Rhizome		Internode of rhizome, average		
		Average	Maximum			
Canada bluegrass	10.7x13.0	2.32	7.9	0.53	4.4	19.7
Kentucky bluegrass	7.3x10.0	3.60	7.9	0.39	9.25	10.0
Quackgrass	18.7x31.3	6.60	22.6	0.59	11.2	5.1
Redtop	5.7x 9.7	1.55	6.7	0.31	5.0	10.5
Reed canarygrass	11.3x13.7	1.56	4.3	0.23	6.81	13.9

TABLE 4.—*Multiple branching of rhizomes in different species of grasses.*

Species	Average total number of rhizomes representing branches of order							
	A	B	C	D	E	F	G	H
Canada bluegrass	3.0	10.3	9.0	3.3	2.0	0.7	0.0	—
Kentucky bluegrass	4.3	9.3	8.7	2.7	0.0	—	—	—
Quackgrass	5.0	15.7	9.0	0.0	—	—	—	—
Redtop	5.3	7.7	4.0	0.0	—	—	—	—
Reed canarygrass	4.3	12.0	11.3	8.7	9.7	4.0	0.3	0.0

Table 3 shows the extent of the direct relationship between the lengths of the individual rhizomes and the area the plants occupy within a given time. Thus, the lengths of the rhizomes of quackgrass, which spreads more rapidly than any other species studied, are greater than the lengths of the rhizomes of any of the other grass-

es. The plants of Kentucky bluegrass have rhizomes with a greater average length than those of the plants of either Canada bluegrass or reed canarygrass, yet the plants of Kentucky bluegrass spread less rapidly than the plants of either one of the other two species.

The explanation for the more rapid growth of the plants of Canada bluegrass and of reed canarygrass than the plants of Kentucky bluegrass may be found in Table 4. From the time the plants were transplanted on May 18, 1931, until April 17 to May 9, 1932, rhizomes of the 4th order of branching had developed on plants of Kentucky bluegrass, of the 6th order on plants of Canada bluegrass, and of the 7th order on plants of reed canarygrass. The more frequent appearance of new rhizomes on the plants of the two latter species more than compensates for their shorter rhizomes as compared with those of Kentucky bluegrass.

The length to which rhizomes grow is partially dependent upon the length of the internodes of which they are composed. The rhizomes of quackgrass, which are longer than those of any other species here described, are composed of internodes longer than those of any of the other grasses.

SUMMARY

The rhizomes of grasses, as well as of other plants, include those forms of elongated rooting stems which grow beneath the surface of the soil.

Both rhizomes and above-ground shoots develop, to a limited extent, at all times when weather conditions are favorable for growth. The new shoots of each type develop in the greatest numbers at fairly definite seasons which overlap to some extent but which do not coincide. In the latitude of northern Ohio, new rhizomes appear in the greatest numbers on plants of the species studied, chiefly during June, July, August, and early September. New above-ground shoots, on the other hand, develop in the greatest numbers from August or September until the close of the growing season, and during April and early May.

A great deal of variation occurs in the way in which rhizomes develop in different species of grasses. In some species, as in Canada bluegrass, the secondary and later rhizomes originate from buds at nodes on older rhizomes at more or less regular intervals. In other species, as Kentucky bluegrass, a very large proportion of rhizomes originate from buds at the bases of above-ground shoots. Rhizomes originating in this way at first grow downward and penetrate the soil, then grow horizontally beneath its surface. The variations in the manner of the origin and the later development of rhizomes on plants of different species of grasses, like the variations in the manner of branching in their inflorescence, result in different types of rhizome systems.

The rate at which a rhizomatious plant spreads depends partly upon external conditions, and partly upon conditions inherent in the plant. The lengths to which the rhizomes grow and the frequency with which new ones develop determine the spread of the area occupied.

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VARIABILITY IN MEASUREMENTS OF HEIGHT AND WIDTH OF MARKET GARDEN PLANTS[1]

DONALD R. WILLARD AND JOHN B. SMITH[2]

IN a recent comparison of the growth of vegetable crops from single and fractional applications of nitrogen,[3] the height and width of several crops were measured at intervals. The results of a simple statistical analysis of the variability of the measurements are presented very briefly in the hope that time may be saved for other workers who contemplate such measurements. No discussion of the various methods for measuring growth rates has been undertaken, nor are the methods used in this study advocated; but because of simplicity, some procedure of this type is often adopted.

The plants measured were grown on 1/30-acre plats of the agronomy field in accordance with accepted cultural practices, and were probably representative of the variability that might be found elsewhere. No unusual precaution was taken to secure uniformity in plant size.

The measurements were made with a caliper improvised from a meter stick with a fixed arm making a right angle at the tip of the stick, and a movable arm, also vertical to the stick, held by a brass clamp. Stations were chosen at spaced intervals, and the spacing was changed for each measuring date. Height measurements for cabbage and tomatoes were taken from the ground line to the highest part of the plant directly above the point where the stem emerged from the soil, and at the portions of the row nearest the predetermined stations for celery, beets, and spinach. Width was measured across the row, and at the place where the height measurements were made.

The probable errors (Table 1) are presented as the percentages of the means to simplify the comparisons. The measurements of cabbage and celery improved in uniformity as the crops grew in size, and this was true in lesser degree for beets. The products of height multiplied by width were less uniform than either dimension alone, showing a tendency for tall plants also to be wide, rather than narrow. The two dimensions were not compensatory.

Measurements were the most uniform for tomato vines and least uniform for celery. If a 10% difference between measurements is considered significant, probable errors of 3% should be allowable. Grouping the crops measured in three categories, this average accuracy for the season could have been approximated by 10 measurements of height or width for spinach and tomatoes, 15 measurements for beets and cabbage, and 20 measurements for celery.

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[2]Assistant Chemist and Chemist, respectively.

[3]SMITH, JOHN B., CRANDALL, FRED K., and FREAR, DONALD E. The relative effect of single and fractional applications of soluble nitrogen on nitrates in soil and plant and on the yields of certain vegetable crops. Jour. Amer. Soc. Agron., 24:203–221. 1932.

TABLE 1.—*The variation in measurements of height, width, and the product of height x width for market garden plants, expressed as the percentages that the probable errors of the means are of the means.*

Crop	Number of plats averaged	Plants measured each plat	Dimension At start	Dimension At finish	$\frac{P_E M \times 100}{M}$							
					May 21	June 3	June 13	June 18	June 26	July 2	July 9	Average
Cabbage	2	30										
Height, cm			10	30	2.49	2.23	1.70	1.71	1.52	1.49	1.74	1.84
Width, cm			13	59	3.19	3.16	2.33	1.97	1.53	1.63	1.35	2.17
Product, cm²			134	1774	4.90	4.65	3.54	3.20	2.64	2.60	2.16	3.38
					June 18	June 26	July 2	July 9	July 16	July 24	July 30	
Tomatoes	3	25										
Height, cm			31	48	1.73	1.62	1.55	1.28	1.44	1.67	1.94	1.60
Width, cm			29	91	1.74	1.83	1.92	1.73	2.04	2.08	1.99	1.90
Product, cm²			905	4193	4.71	2.57	2.58	2.40	2.56	2.88	2.69	2.91
					Aug. 7	Aug. 20	Aug. 27	Sept. 4	Sept. 11	Sept. 19	Sept. 27	
Celery	3	50										
Height, cm			11	40	2.04	1.97	2.65	2.56	1.35	1.23	1.07	1.84
Width, cm			13	58	2.32	2.09	2.09	1.91	1.38	1.26	1.10	1.74
Product, cm²			140	2358	3.57	3.77	4.20	4.06	2.46	2.19	1.90	3.16
					Sept. 11	Sept. 19	Sept. 26	Oct. 5	Oct. 14			
Beets	2	50										
Height, cm			21	32	1.71	1.32	1.11	1.14	1.76	—	—	1.41
Width, cm			23	36	2.12	1.44	1.41	1.28	1.53	—	—	1.56
Product, cm²			493	1181	3.18	2.16	2.01	2.07	2.57	—	—	2.40
					Sept. 19	Oct. 5	Oct. 14					
Spinach	2	50										
Height, cm			14	16	1.36	1.48	1.60	—	—	—	—	1.48
Width, cm			18	27	1.32	1.21	1.24	—	—	—	—	1.26
Product, cm²			250	392	2.47	2.32	2.40	—	—	—	—	2.40

RELATION BETWEEN FALLOWING AND THE DAMPING-OFF OF ALFALFA SEEDLINGS[1]

C. O. GRANDFIELD, C. L. LEFEBVRE, AND W. H. METZGER[2]

AN experiment was conducted from 1930 to 1935 at the Kansas Agricultural Experiment Station in cooperation with the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, to determine the length of fallow period necessary to restore the subsoil moisture removed by a preceding alfalfa crop. Alfalfa was seeded each fall, beginning with the fall of 1930, on two series of plats one of which had been fallowed and the other cropped with a rotation of sorghum, corn, wheat, oats, and alfalfa. Thus, the fallow period was lengthened each year until, in 1934, the alfalfa was sown on soil that had been fallowed 5 years and also on soil that had been continuously cropped. As the period of fallow increased to 3 years, a decrease in the vigor of alfalfa seedlings became apparent; this reduction in vigor becoming even more pronounced following 4 and 5 year periods of fallowing.

The first symptoms of the diseased condition were a retardation of growth, lack of vigor, and finally a yellowing of the entire plant. Fig. 1 shows the stand resulting from the seeding made in the fall of 1934 after 5 years of fallow. Many of the primary roots soon after emergence of the young seedlings were found to be decayed below the surface of the soil. Localized lesions frequently developed on the hypocotyls of the seedlings prior to their emergence. If the plants survived, it was because lateral roots had developed above the decayed portion. The retardation of growth or the dying of the plants seemed to be the result of the loss of a part or all of the root system. Those plants which survived gradually developed a root system capable of sustaining normal plant growth and the earlier injurious effect of the disease was not evident after the first cutting the following spring.

The appearance of the diseased seedlings is shown in Fig. 2. The seedlings at the left labeled No. 1 show the presence of small, brown cankers on the roots which are characteristic symptoms of an early stage of the disease. In No. 2 the canker is girdling the root, while in No. 3 the roots have rotted off completely and brown spots have developed on the hypocotyls. In No. 4, the lower part of the root has decayed and sloughed off and lateral roots have formed just above the injured portion. From field counts made in measured areas of the 1933 seeding after 4 years of fallowing, 55% of the plants were diseased. From measured areas of the 1934 seeding after 5 years

[1]Cooperative Investigation of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Kansas Agricultural Experiment Station, Manhattan, Kan. Contribution No. 248, Department of Agronomy and No. 351, Department of Botany. Received for publication July 18, 1935.

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of fallowing, 33% of the stand obtained remained the next spring, while 70% of the plants on the cropped plats survived.

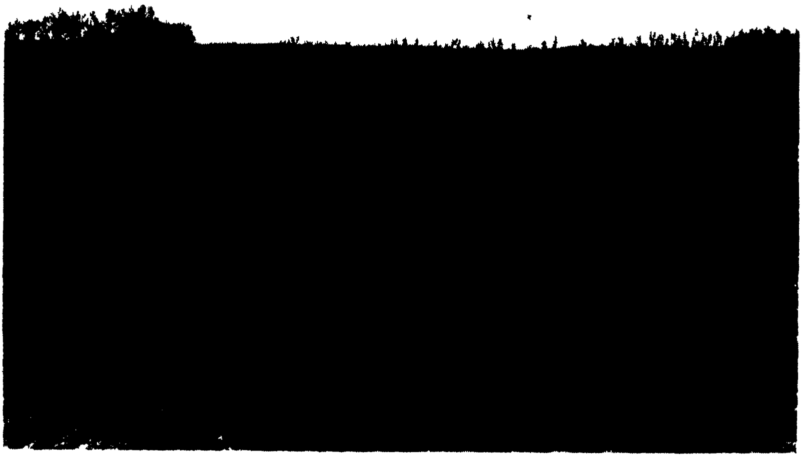

FIG. 1.—Alfalfa seeded in the fall of 1934, after 5 years of fallow (foreground) and after 5 years cropping system (background).

FIG. 2.—Diseased alfalfa seedlings from soil fallowed 5 years.

In order to determine the effect of the disease on the development of the root system of older seedlings (80 days), a block of soil 1 foot wide, 4 feet long, and 2 feet deep was removed from a cropped and also from a fallowed plat. The soil was carefully washed from the al-

falfa roots, which were then measured as to diameter and length. The data in Table 1 show that the cropped soil contained a greater number of large and long-rooted plants in a measured area than the fallowed soil. It was also evident from observation that there were many more lateral and fibrous roots on the plants from the cropped soil.

TABLE 1.—*Alfalfa roots classified according to diameter 1 inch below the crown and according to length from a 4 square foot area in both fallowed and cropped plats.*

Plat treatment	Number of plants with a root diameter of							Total number plants
	0–½ mm	½–1 mm	1–1½ mm	1½–2 mm	2–2½ mm	2½–3 mm	3 mm	
Fallow....	0	17	60	50	26	—	—	153
Cropped..	0	11	29	32	64	15	5	156
	No. of plants with roots of the length indicated							
	0–15 cm	15–25 cm	25–45 cm	45–60 cm				
Fallow....	69	38	15	31				153
Cropped..	11	39	32	74				156

PRELIMINARY TRIALS

In an attempt to determine the cause of the diseased condition of the seedlings, soil was brought into the greenhouse from both the fallowed and cropped plats, subjected to various treatments as shown in Table 2, and then seeded to alfalfa. The results obtained from an examination of more than 20,000 seedlings in these experiments indicate that the diseased condition was caused by some pathogenic organism, since any form of partial or complete soil sterilization seemed to decrease the number of diseased plants. Three forms of sterilization were used. In the first, soil was steamed in an autoclave

TABLE 2.—*Greenhouse and field counts showing the effect of different soil treatments on the occurrence of diseased alfalfa seedlings.*

Treatment	Number of tests	Average number seeds planted	Average number plants	Percentage of diseased plants
	Fallowed Soil			
No treatment............	4	266	141	72
Dry heat sterilization.....	4	235	183	6
Steam sterilization........	2	237	177	7
Formalin................	1	240	178	20
CaO....................	2	231	160	39
Aerated.................	1	273	167	65
Wheat straw (chopped)...	2	203	90	74
	Cropped Soil			
No treatment............	3	231	172	13
Aerated.................	1	217	152	18

at 15 pounds pressure for 3 hours; in the second it was treated with dry heat in an oven at 100°C for 24 hours; and in the third the soil was sprayed with formalin, mixed, and covered for 48 hours. The steam and dry heat sterilizations of the fallowed soil reduced the number of diseased seedlings to 7 and 6%, respectively, while the formalin treatment reduced the number to 20%.

Fallowing had a tendency to deflocculate the soil which became tight and compact slightly below the surface with the result that aeration of much of the subsurface soil was somewhat inhibited. Additional experiments were conducted to learn what effect certain chemical and physical characteristics of the soil might have upon the inception of the disease. Organic matter in the form of chopped wheat straw was added to certain lots of soil taken from fallowed plats in order to improve its physical condition and another portion of the fallowed soil was placed in a thin layer before an electric fan and stirred frequently for 48 hours in order to aerate it thoroughly. The seedling counts from these treatments are nearly the same as the untreated fallow soil. In one instance not recorded in the table, pure sand was added to change the physical condition of the soil, but there was no decrease in the number of diseased seedlings.

Calcium oxide at the rate of 10,000 pounds per 2,000,000 pounds of soil was added to one lot of soil. At this rate there seemed to be some sterilizing effect and a decrease in the number of diseased plants resulted.

ISOLATION OF THE ORGANISM

As the results of the preliminary trials indicated that the diseased condition of the seedlings was not due to adverse physical or chemical factors, an effort was made to isolate some organism suspected of parasitizing the plants. A number of diseased plants was collected from the field, their roots washed in sterile distilled water, dried between sheets of sterile filter paper, and placed on corn meal agar, while others were left in distilled water several days before being placed on agar. After a day or two, hyphae emerged from the roots, and by cutting the tips of the radiating strands of mycelium with a sterile scalpel, pure cultures of various fungi were obtained. These belonged for the most part to the Fusarium, Helminthosporium, Trichoderma, and Pythium groups, with the last strongly predominating. These various fungi were then grown on a mixture of sterile oats and barley and different amounts were used to inoculate sterile soil that was later planted to alfalfa. Of the several fungi tested only members of the genus Pythium were pathogenic to the alfalfa seedlings.

In order to make an additional test of the pathogenicity of the Pythiums, one of the isolates was tested by thoroughly mixing various amounts of inoculum with soil adjusted to a definite acidity. It was reported by Buckholtz[3] in 1934, that a damping-off of alfalfa seedlings caused by a species of Pythium was especially severe in acid soils. It appeared desirable, therefore, to determine the relation-

[3]Buckholtz, W. F. The rôle of damping-off disease in relation to failure of alfalfa stands on some acid soils. Science, 80:503. 1934.

ship of soil reaction to the activity of the organism isolated from Kansas soils. Flats were filled with 25 pounds of sterilized soil in which the reaction had been adjusted by addition of appropriate amounts of sulfuric acid or calcium hydroxide, and various amounts of inoculum were mixed with the top ¾ inch of the soil. The results of this test are summarized in Table 3.

TABLE 3.—*Effect of different amounts of inoculum and soil acidity on the emergence of alfalfa seedlings.*

Approximate pH value of the soil	Percentage of plants emerging when the following amounts of inoculum were used per 25 pounds of soil					Controls %
	113 grams	56 grams	30 grams	15 grams	7 grams	
3	—	—	—	1	1	2
4	0	14	19	34	64	82
5	1	5	15	23	48	84
6	1	2	10	18	44	84
7	2	2	4	12	41	89
8	2	1	3	20	38	86
9	—	—	—	23	38	83

It is evident from these data that, as would be expected, a soil with a pH as low as 3 is too acid for alfalfa plants since even the control had a very poor stand. It was also apparent that, as the amount of inoculum was reduced, the percentage of plants emerging increased. In this test, 56 grams of sterile oat-barley mixture was used in the control because it had been found in previous experiments that the amount of sterile oat-barley used had little or no effect on the stand of alfalfa. A similar test was made using only 7 and 15 grams of inoculum at various degrees of soil acidity. In this test the seedlings were carefully removed from the soil about 7 days after emergence and the number of diseased plants recorded. A summary of the results is presented in Table 4. It is again apparent that the presence of a larger amount of inoculum in the soil increased the severity of the disease. The data in Table 4, represented graphically in Fig. 3, indicate that the disease was most severe in soils ranging in reaction from pH 6 to pH 8, inclusive, and that when the pH was below 6 the percentage of diseased plants decreased materially.

TABLE 4.—*Effect of concentration of inoculum and degree of soil acidity on the damping-off of alfalfa seedlings caused by a species of Pythium.*

pH value	Percentage germination controls	Percentage diseased plants		
		Controls	7-gram inoculum per 25 lbs. of soil	15-gram inoculum per 25 lbs. of soil
4.05	87	17	33	43
5.08	90	4	26	44
6.01	89	13	67	91
6.94	91	5	49	88
7.70	86	9	65	74
8.21	84	15	59	58

Tests with inoculated soil in tanks in which the soil temperature was held at varying levels from 15° to 37°C indicated that the fungus was much more virulent at the lower temperatures. At the higher temperatures many infected plants survived. These results seem to be in agreement with those found under field conditions during the

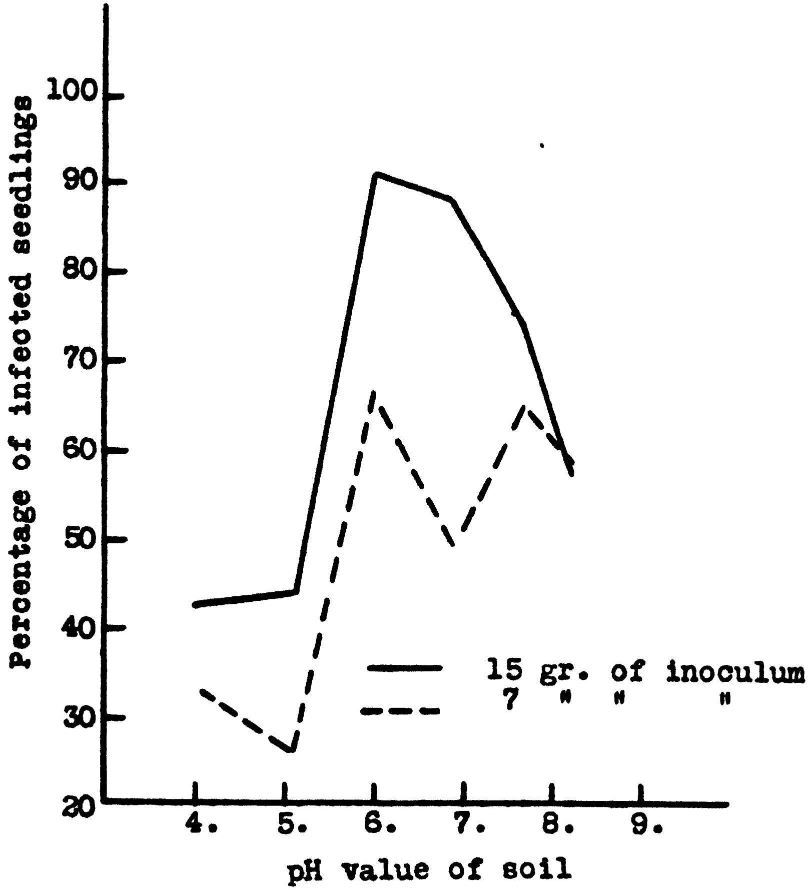

FIG. 3.—Relationship of the pH value of the soil to the percentage of alfalfa seedlings infected by a species of Pythium.

exceptionally hot summer of 1934. The high soil temperatures seemed to have a partial sterilizing effect as seed planted on fallowed soil that year (1934) produced better stands than those from plantings made on similar soil the previous fall when the temperatures were more moderate.

Attempts at developing methods of controlling the disease or increasing the percentage of seed germination on fallowed soil in the field have not been made, but investigations on this phase are now being conducted. Also the effect of the fungus on seedlings of various legumes and other crop plants is being studied.

DISCUSSION

Fallowing soil before seeding alfalfa is commonly practiced for the purpose of storing moisture and possibly as a result of this moisture storage more favorable conditions were brought about in the soil for the development of *Pythium* spp. From the results presented it may be concluded that the disease was caused by a fungus which in this experiment became more prevalent as the length of the fallow period increased. The length of fallow period necessary to cause a sufficient accumulation of the fungus to be harmful to alfalfa seedlings was not determined, but it is known that after 2 years of fallow the stand was materially reduced in some instances and also that 1 year of fallow has caused a weakening of the plants to a noticeable degree.

The data presented from the greenhouse tests show that as the amount of inoculum was increased the number of seedlings emerging from the soil was greatly decreased, indicating that where the organism is concentrated in the soil seedlings are killed soon after germination and also that the percentage of diseased plants increases as the pH value approaches the neutral point, reaching a maximum between pH values of 6 to 8. The differences recorded in the germination under the different pH values are small and probably are not significant. The soil on which the fallow experiment was conducted had a pH of 5.50 and grows alfalfa well without liming. After 5 years of fallowing the pH value was 5.21 which alone did not affect the growth of alfalfa.

SUMMARY

During the years 1930 to 1935, inclusive, alfalfa seed planted on soil fallowed for periods varying from 1 to 5 years have produced seedlings with less vigor and eventually poorer stands than seedlings grown on soil previously cropped. While the results of this experiment indicated that reduced stands would not result until after 3 years of fallow, observations in other sections of Kansas suggest that the difficulty might result from only 1 to 2 years of fallow.

Reduced stands proved to be due to the death of seedlings resulting from infection by fungi belonging to the genus Pythium. The organism was most pathogenic in soils in which the pH varied from 6 to 8.

A TABLE FOR TRANSFORMING THE CORRELATION COEFFICIENT, r, TO z FOR CORRELATION ANALYSIS[1]

H. H. Love[2]

THE purpose of this paper is to set forth a table for transforming the correlation coefficient, r, to z, for use in correlation analysis, in accordance with the methods presented by Fisher.[3] At the same time some examples are given to demonstrate the method of using the table.

In connection with correlation studies it is often important to compare correlation coefficients. That is, there may be two correlation values obtained for the same characters under different conditions, or correlation coefficients obtained for various characters, and in either case a comparison of these correlation coefficients may be valuable. The usual method of making such comparisons is to determine the probable errors or the standard errors of the correlation coefficients and then obtain the difference between the correlation coefficients and the error of this difference, which is the square root of the sum of the squares of the two errors. The difference between the correlation coefficients is then interpreted on the basis of the value of the error of the difference. Unless the difference is three or more times the probable error or two or more times the standard error, it is not considered significant. In some investigations it is also desired to combine correlations that have been determined from several populations of similar material, either by averaging the correlation coefficients or obtaining the weighted average.

It is recognized that correlation coefficients obtained from a small number of observations are not so reliable as when based on a larger number and at the same time, as pointed out by Fisher, the correlation coefficient, r, obtained from a small number of individuals is not distributed normally. For this reason it is better to use some means of comparing correlations based on a constant which is a function of the correlation coefficient but which by nature is more nearly normally distributed. Fisher suggests such a constant, z, which is obtained from

$$z = \tfrac{1}{2}\{\log_e(1 + r) - \log_e(1 - r)\}$$

or

$$z = r + 1/3r^3 + 1/5r^5 + 1/7r^7 + 1/9r^9 \ldots\ldots$$

The value of z may be calculated from either of the above equations. If tables of the natural logarithms are available it is a simple matter to substitute the values for $\log_e(1 + r)$ and $\log_e(1 - r)$ and obtain the value of z. If tables of natural logarithms are not available the common logarithms may be used and the values of

[1]Paper Number 213, Department of Plant Breeding, Cornell University, Ithaca, N. Y. Received for publication August 3, 1935.

[2]Professor of Plant Breeding.

[3]FISHER, R. A. Statistical Methods for Research Workers. London: Oliver & Boyd. Ed. 5. 1934.

the common logarithms multiplied by the factor 2.302585093 to convert them to natural logarithms. For example, if an r value of .50 has been obtained, the z value is determined from tables of common logarithms as follows:

$\log(1 + r) = \log 1.50 = .1760913$ and $.1760913 \times 2.302585093 = .405465$

$\log(1 - r) = \log .50 = 9.6989700 - 10$ and $9.6989700 - 10 \times 2.302585093 = 9.306853 - 10$ and $\frac{1}{2}\{\log_e(1 + r) - \log_e(1 - r)\} = \frac{1}{2}\{.405465 - (9.306853 - 10)\} = .5493$

This gives a z value to four decimal places of .5493. With the second equation, where

$$z = r + 1/3r^3 + 1/5r^5 + 1/7r^7 + 1/9r^9 \ldots\ldots$$

substituting the value of r, .50, and obtaining the values for the first five terms, z is found to be .54925.

When tables of natural logarithms are not available these methods of determining z are laborious and it is desirable to have a table which will make it possible to change from r to z or from z to r directly. Fisher has published such a table, in which corresponding values of r for certain values of z are given. It is often more convenient to obtain the z value directly from the value of r, and for this reason the table presented here as Table 1 has been prepared by Miss Frances Feehan of the Department of Plant Breeding at Cornell University.

This table gives the values of z to four decimals for values of r from .01 to .90 read to two decimals. For the higher values of r three decimals have been retained, proceeding by steps of .005. For all ordinary comparisons it is sufficient for practical purposes to obtain z from r by interpolating from the values given in this table. For example, for an r value of .337 it is found by interpolating from Table 1 that the corresponding z value is .3507. If z had been obtained exactly by taking the common logarithms and converting them to the natural logarithms and substituting in the first equation above, the same value for z, .3507, would be obtained. Taking another value for r, .712, and interpolating from the table, the z value is found to be .8913. If this z value had been obtained by the use of logarithms as above the result would have been .8912, a difference of .0001. For very high values of r the differences between the z values obtained by direct interpolation from the table and those determined according to the method above will be greater, but for most cases interpolation from the table will be sufficiently accurate. Where greater accuracy is desired, the value of z should be determined from r by means of logarithms, following the method illustrated above, or by reference to Fisher's table.

As stated above, the principal reason for transforming r to z is that z is more nearly normally distributed than is r, especially for small samples, and even with large samples r is not distributed normally for high correlations. Therefore, more exact comparisons may be made by using the z values rather than the r values. The methods of comparison are similar, that is, the significance of the difference between either the r or z values is based on the standard error of

the difference. In order to complete the comparison by means of the z values it is therefore necessary to determine the standard error of the z values. The formula used for the standard deviation of r is

$$\sigma^r = \frac{1-r^2}{\sqrt{N'-1}}$$

This value is in error due to the fact that the true value of r cannot be known, and especially does this hold for small samples. The standard deviation of z is approximated very closely from

$$\sigma_z = \frac{1}{\sqrt{N'-3}}$$

The formula for σ_2 is simpler in form and it is evident that it is independent of the correlation coefficient. A more convenient application is to deal with the variance, or

$$\sigma^2{}_z = \frac{1}{N'-3}$$

TABLE 1.—*Table of z values, for values of r from .01 to .995.*

r	z	r	z	r	z	r	z
.01	.0100	.31	.3205	.61	.7089	.905	1.4992
.02	.0200	.32	.3316	.62	.7250	.910	1.5275
.03	.0300	.33	.3428	.63	.7414	.915	1.5574
.04	.0400	.34	.3541	.64	.7582	.920	1.5890
.05	.0500	.35	.3654	.65	.7753	.925	1.6226
.06	.0601	.36	.3769	.66	.7928	.930	1.6584
.07	.0701	.37	.3884	.67	.8107	.935	1.6967
.08	.0802	.38	.4001	.68	.8291	.940	1.7380
.09	.0902	.39	.4118	.69	.8480	.945	1.7828
.10	.1003	.40	.4236	.70	.8673	.950	1.8318
.11	.1104	.41	.4356	.71	.8872	.955	1.8857
.12	.1206	.42	.4477	.72	.9076	.960	1.9459
.13	.1307	.43	.4599	.73	.9287	.965	2.0139
.14	.1409	.44	.4722	.74	.9505	.970	2.0923
.15	.1511	.45	.4847	.75	.9730	.975	2.1847
.16	.1614	.46	.4973	.76	.9962	.980	2.2976
.17	.1717	.47	.5101	.77	1.0203	.985	2.4427
.18	.1820	.48	.5230	.78	1.0454	.990	2.6467
.19	.1923	.49	.5361	.79	1.0714	.995	2.9945
.20	.2027	.50	.5493	.80	1.0986		
.21	.2132	.51	.5627	.81	1.1270		
.22	.2237	.52	.5763	.82	1.1568		
.23	.2342	.53	.5901	.83	1.1881		
.24	.2448	.54	.6042	.84	1.2212		
.25	.2554	.55	.6184	.85	1.2562		
.26	.2661	.56	.6328	.86	1.2933		
.27	.2769	.57	.6475	.87	1.3331		
.28	.2877	.58	.6625	.88	1.3758		
.29	.2986	.59	.6777	.89	1.4219		
.30	.3095	.60	.6931	.90	1.4722		

The variance of z is equal to the reciprocal of $N' - 3$ and the standard error is the square root of this variance.

To show the application of Table 1 in the comparison of two correlation coefficients, the correlations between total yield of plant and average number of kernels per culm in oats for two different years are used. The correlation coefficients are .769 and .680, and the problem is to determine whether there is a real difference in the correlation of these two characters for the different years, or, in other words, whether environment has influenced the correlation. The steps in the method of comparison are given in Table 2.

The z values corresponding to the values of r are obtained from Table 1 by direct interpolation. For $r = .769$ the z value is 1.0179 and for $r = .680$ the z value is .8291, and the difference is .1888. There were 500 individuals in the population in the first year and 400 individuals in the second year, so the $N' - 3$ values for determining the standard errors are 497 and 397, respectively. The reciprocals of these $N' - 3$ values are obtained, giving the square of the standard error, or variance, of each z value. Since in this comparison the standard error of the difference is desired, these reciprocals are summed, giving the sum of the squares of the errors of the z values, and the square root of this sum, or .0673, is the standard error of the difference. The difference between the z values is, therefore, $.1888 \pm .0673$. To be significant this difference must be two or more times its standard error, and on this basis there is a real difference between the correlation values used in this comparison. The conclusion is that environment has affected the correlation between these characters.

Another comparison is given in the second part of Table 2. In this case the characters number of culms per plant and height of plant in oats have been correlated with total yield of plant. The resulting correlation coefficients are compared to determine which character seems to have the greater effect on yield for this particular lot of data. The difference between the z values is $.4101 \pm .0634$, which is highly significant and indicates that for these data number of culms per plant has a greater effect on total yield than does the height of plant.

TABLE 2.—*Method of comparing two correlation coefficients.*

	r	z	N'-3	Reciprocal N'-3
Correlations between total yield of plant in grams and average number of kernels per culm in oats for two different years				
First year	.769	1.0179	497	.00201207
Second year	.680	.8291	397	.00251889
	Difference = .1888 ± .0673			Sum = .00453096
Correlations between total yield of plant and number of culms per plant and between total yield of plant and height of plant in oats.				
Number of culms	.850	1.2562	497	.00201207
Height of plant	.689	.8461	497	.00201207
	Difference = .4101 ± .0634			Sum = .00402414

As already stated, this means of comparing correlation coefficients is more accurate than by using r directly, and the use of the z values is also more accurate for combining the results from several correlations. The purpose in combining correlation coefficients is to obtain a general value, or a weighted value, based on the correlations obtained from several independent studies of the same characters. For example, the same two characters may have been correlated for different years or under different conditions, and it is desired to combine these correlations, giving one general figure or constant weighted in accordance with the results obtained from the individual comparisons. The method of combining correlation coefficients by means of the z values is illustrated in Table 3.

TABLE 3.—*Combination of correlations.*

	r	z	N'-3	$(N'$-3$)\,z$
Correlations between total yield of plant in grams and average number of kernels per culm in oats for two different years				
First year.........	.769	1.0179	497	505.8963
Second year.......	.680	.8291	397	329.1527
Weighted values...	.732	.9341 ±.0334	Sum = 894	Sum = 835.0490
Correlations between average weight of kernels per plant and average yield of culm per plant in oats for four different years				
First year.........	.464	.5024	822	412.9728
Second year.......	.337	.3507	497	174.2979
Third year........	.225	.2289	397	90.8733
Fourth year.......	.429	.4587	397	182.1039
Weighted values...	.386	.4071 ±.0218	Sum = 2113	Sum = 860.2479

Using the same correlation coefficients as in the first example in Table 2, the z values and $N' - 3$ values are obtained as before. Each z value is multiplied by the corresponding value of $N' - 3$, which gives a value weighted in accordance with the number in the population. These weighted values are summed and a weighted z value, .9341, is obtained by dividing this sum by the sum of the $N' - 3$ values. By direct interpolation from Table 1 the corresponding value of r for this weighted z value is found to be .732.

To determine whether this z value of .9341 is significant, in other words whether there is real correlation, the standard error is determined from the square root of the variance. This is the square root of the reciprocal of the sum of the $N' - 3$ values, which in this case is $\sqrt{\frac{1}{894}}$. This gives a standard error of .0334 for $z = .9341$, which indicates that z is highly significant and there is a fairly high correlation between the two characters.

It is possible to combine several correlation coefficients in this manner, continuing the steps as in the second example in Table 3. The data used here are the results obtained from correlating the average weight of kernels per plant and the average yield of culm

per plant in oats for four different years. The individual correlation coefficients vary considerably, and by combining them on the basis of the z values a general value, .4071 ± .0218, is obtained, from which r is found to be .386.

These examples illustrate the application and usefulness of the table giving corresponding r and z values. As stated above, this table making it possible to read z directly from r is presented for the convenience of investigators. For nearly all practical applications sufficient accuracy is obtained by direct interpolation from the values in the table. However, where greater accuracy is desired the exact value of z to several decimal places may be obtained by the methods explained above.

BAGASSE AND PAPER MULCHES[1]

O. C. MAGISTAD, C. A. FARDEN, AND W. A. BALDWIN[2]

STRAW and paper mulches have been widely used in the commercial production of fruits and vegetables. The use of sugar cane bagasse as a mulch was used in Hawaii about 1930 by the Haleakala Pineapple Company which later became the Maui Pineapple Company. The beneficial effects obtained with pineapples led to a large scale experiment in which bagasse mulch was compared with paper mulch and with no mulch. In this experiment records of soil moisture, soil temperature, available soil nitrogen, and fruit yields were obtained. These data are presented in this paper.

REVIEW OF LITERATURE

Much of the literature on the use of paper mulches was reviewed by Hutchins (5)[3] in 1933, and only additional references will be included here. Mulches of this type definitely reduce weed growth and in this manner reduce cultivation and hoeing costs. In addition, mulches in general improve the growth of economic plants (6). One reason for better plant growth is that the soil temperatures are higher with reduced fluctuations under mulches, especially paper (8). Furthermore, reduction in weed growth is coupled with the effect of the mulch in reducing evaporation, resulting thereby in a conservation of soil moisture. Because of higher soil temperatures and greater soil moisture, biological processes in the soil are considerably accelerated. This results in a greater liberation of plant food, especially nitrates.

There appear to be no references on the use of sugar cane bagasse as a mulch, but this material should act as do straw mulches. If the mulch is incorporated with the soil, or if soluble material having a high carbon-nitrogen ratio is leached into the soil, a reduction in available nitrogen in the soil occurs. Under such conditions nitrates do not accumulate in the soil until the carbon-nitrogen ratio has been lowered (1, 9, 4).

EXPERIMENTAL PROCEDURE

The plan of the experiment consisted of 11 treatments involving the use of bagasse and paper as mulches. Two levels of nitrogen fertilization and two levels of bagasse representing light and heavy applications constituted the variables. Treatments and replications are shown in Table 1.

It will be observed that treatments B_3, C_3, and D_3 are duplicates of B_2, C_2, and D_2, respectively. It was originally intended that treatments B_3, C_3, and D_3 would receive iron sulfate spray while treatments B_2, C_2, and D_2, otherwise similar, would receive water only. The iron sultate spray treatments, however, were made uniformly on all plats. Consequently B_3 is a duplicate of B_2; C_3 of C_2; and D_3 of D_2. An earlier fertilizer experiment in this locality showed that the use of phosphorus and potash did not increase yields. Hence the addition of these nutrients were omitted in this experiment.

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[2]Chemist, Assistant Chemist, and Assistant Agriculturist, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 825.

TABLE 1.—*Treatments and replications employed in the experiment.*

Treatment symbol	Number of replications	Treatment	
		Lbs. N per acre	Kind of mulch
A_1	4	300	None
A_2	4	600	None
B_1	6	300	Paper
B_2	6	600	Paper
B_3	6	600	Paper
C_1	6	300	8 tons bagasse
C_2	6	600	8 tons bagasse
C_3	6	600	8 tons bagasse
D_1	6	300	16 tons bagasse
D_2	6	600	16 tons bagasse
D_3	6	600	16 tons bagasse

The experiment was installed on November 13, 1931. However, owing to a shortage of material, application of bagasse was not completed until 6 weeks later. The treatments occupied 62 plats. Each plat consisted of two four-row beds 150 feet long and systematically arranged by blocks. At a later date, however, the number of plats was reduced by omitting some of the A plats from the experiment. Some plats of the A treatments were retained to serve as a measuring stick with which to compare results with paper and bagasse treatments. Later developments, however, indicated that pineapples grew very poorly on the A treatments, and hence these treatments were omitted from further consideration 1 year after installation. This action finally reduced the number of plats from 62 to 54. There were 19,100 plants per net acre, planted in the usual manner (7).

The fertilization schedule and dates of application for the plant and ratoon crops are shown in Table 2.

TABLE 2.—*Date and rate of applications of nitrogen to plant ratoon crops.*

Treatments	Nitrogen in pounds per acre						
	Plant crop			Ratoon crop			Total for cycle
	At planting	March 11, 1932	Dec. 10, 1932	Apr. 19, 1933	March 20, 1933	Febr. 21, 1934	
A_1 B_1 C_1 D_1	100	100	100	80	80	160	620
A_2 B_2 B_3 C_2 C_3 D_2 D_3	200	200	200	80	80	160	920

The amounts of nitrogen added to ratoons were left at a low level in order not to mask earlier effects. The dates of these applications were later than the ordinary plantation practice, due to the fact that the extremely dry weather during the first ratoon year left much of the fertilizer undissolved at times when plants generally received fertilizers.

Treatment effects on soil temperature, soil moisture, nitrification, and fruit yield served as measures for judging the superiority of one treatment over another.

RESULTS

TEMPERATURE RECORDS

Soil temperature records were obtained by means of recording soil thermographs manufactured by Julien P. Friez & Sons. Three soil thermographs were used, one each under paper, bagasse, and no mulch. The thermometer tube of each recorder was placed horizontally with the soil surface at a depth such that there were 2 inches of soil above it. These were installed January 5, 1932, and records under paper and bagasse were obtained until December 22, 1934, except for intervals of a few days when the clocks stopped. The temperature recorder under bagasse treatment gave successively lower temperatures in April and May 1933 and was replaced by a new instrument on June 17. At the end of the test, as well as at the beginning, all recorders were checked for accuracy and were found to be reliable with the exception noted above.

Maximum and minimum air temperatures read weekly were obtained in a standard shelter during a part of 1933.

The soil temperature results are condensed in Table 3.

SOIL MOISTURE

It has been demonstrated many times that the use of paper mulch especially in dry regions, has caused increased plant growth and fruit weights of pineapples. This increase is attributed in a large measure to increased soil moisture due to the use of paper mulch.

In order to compare and measure the action of bagasse against paper mulch on this growth factor, composite moisture samples were taken at three depths from all plats, except the A_3, B_3, C_3, and D_3 plats, *viz.*, 0 to 6 inches, 6 to 12 inches, and 12 to 24 inches taken at approximately 2-month intervals. The first sampling was taken January 1, 1932, about 2 months after the installation of the experiment, and nine samplings were obtained thereafter.

By omitting the B_3, C_3, and D_3 plats, 44 plats in all were sampled each time, and gave a total of 132 soil samples for each sampling. After the fifth sampling, however, the number taken was cut to 108 due to the omission of all the A plats. Up to and including the last series of samples which was taken March 16, 1934, the total number taken was 1,200 and is too voluminous to record in this report. However, Fig. 1 presents the data in graphic form and represents the average soil moisture contents of the replicate plats on the dates sampled for each treatment at the three depths.

WILTING COEFFICIENTS

The percentage of moisture in the soil when quick-growing indicator plants wilted was determined by the method outlined by Briggs and Shantz (2), except that lead foil was used as a seal in place of paraffin. All joints and edges received paraffin in addition. The indicator plants were sunflowers and cowpeas, and these were each grown in triplicate gallon cans. A total of 38 individual determinations from six cans gave a mean wilting coefficient of 18.7 with a standard deviation of 1.1% of the mean value.

TABLE 3.—*A condensed table of soil and air temperatures with the soil temperatures taken at a depth of 2 to 3 inches and all values given in degrees F.*

Month	Soil				Paper				Bagasse			
	Mean Max.	Variance	Mean Min.	Variance	Mean max.	Variance	Mean min.	Variance	Mean max.	Variance	Mean min.	Variance
							1932					
Jan.	84.64	13.70	70.02	3.09	89.50	17.76	67.93	3.36	76.52	1.86	69.81	1.20
Feb.	78.08	25.23	67.02	4.14	82.05	45.05	65.72	4.76	73.66	5.37	67.95	1.62
Mar.	88.03	22.55	70.32	1.35	93.98	42.69	68.15	9.75	78.84	7.97	69.68	3.41
Apr.	91.56	11.83	74.35	2.80	93.95	27.58	70.77	2.82	80.50	4.50	70.40	9.03
May	95.08	8.64	77.90	4.08	94.70	14.77	73.24	2.75	83.05	4.09	71.90	1.75
June	97.30	9.70	80.30	2.20	93.92	9.64	74.56	2.53	85.20	4.25	73.75	1.48
July	99.43	7.58	81.82	2.61	93.55	7.08	75.91	2.84	87.26	3.26	75.39	1.07
Aug.	99.27	7.56	82.01	2.36	92.63	7.06	76.04	2.33	87.02	3.47	75.69	1.31
Sept.	96.38	6.84	80.01	3.33	89.07	6.50	74.36	2.25	84.53	3.46	74.35	1.44
Oct.	94.54	11.16	78.24	1.90	85.35	6.16	72.31	2.01	82.07	4.01	72.65	1.17
Nov.	87.08	19.20	73.82	11.96	79.07	8.53	69.78	4.48	75.45	9.42	68.65	6.31
Dec.	85.17	7.33	69.93	2.44	74.88	1.51	66.06	2.01	70.38	1.26	63.74	2.34
Annual	91.38		75.48		88.55		71.24		80.37		71.16	
							1933					
Jan.	Air temperatures based on weekly readings of maximum and minimum thermometers				73.32	1.67	64.41	1.04	Temperature data from Jan. to July omitted because of unreliability; new recorder installed June 17.			
Feb.					73.10	3.63	65.57	3.00				
Mar.					73.03	6.18	64.66	2.10				
Apr.	87.9		52.8		73.89	5.67	65.24	2.44	—	—	—	—
May	89.6		56.0		76.26	1.41	67.07	0.92	—	—	—	—
June	90.4		58.1		76.04	1.69	67.43	0.68	—	—	—	—
July	91.9		57.7		77.06	0.83	68.62	1.62	77.95	0.92	70.88	1.34
Aug.	93.3		57.5		76.82	1.86	67.65	0.97	77.55	1.64	70.29	0.67
Sept.	94.4		57.8		75.70	1.45	66.76	0.81	77.32	0.63	70.03	0.57
Oct.	92.9		56.5		73.44	1.19	66.19	1.16	74.96	0.93	68.79	0.64
Nov.	89.8		54.0		68.79	8.79	62.83	5.78	71.25	4.01	66.27	3.49
Dec.	87.5		50.9		67.30	0.71	61.74	2.43	69.71	0.67	65.50	1.52
Annual					73.73		65.68					

NITROGEN DETERMINATIONS

Composite samples for nitrate and ammonia determination were taken from all plats which received 300 pounds of nitrogen per acre. Nitrates were determined by the method of Harper (4) and ammonia by a direct distillation of an acid sodium chloride extract of soil. Ammonia and nitrate content of the soil at two depths, 0 to 6 inches and 6 to 12 inches, were determined. Results obtained are visualized in Fig. 2. Nitrate content is superimposed on ammonia content for the same treatment.

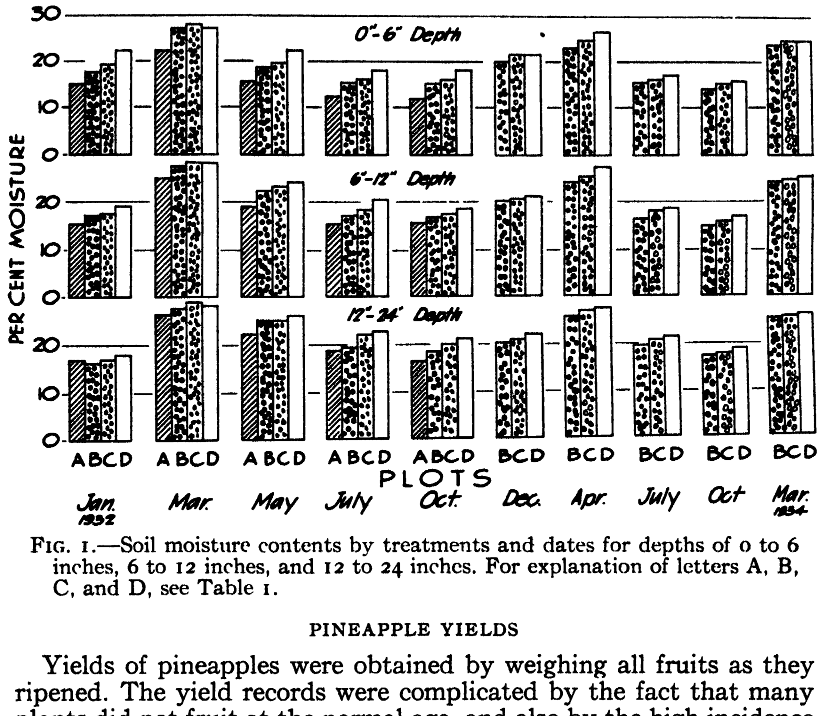

FIG. 1.—Soil moisture contents by treatments and dates for depths of 0 to 6 inches, 6 to 12 inches, and 12 to 24 inches. For explanation of letters A, B, C, and D, see Table 1.

PINEAPPLE YIELDS

Yields of pineapples were obtained by weighing all fruits as they ripened. The yield records were complicated by the fact that many plants did not fruit at the normal age, and also by the high incidence of fasciated fruits.

Table 4 shows the total number and weight of fruits collected from each treatment. The last column shows the average number of fasciated fruits found in the 1934 harvest. There were very few fasciated fruits in the summer of 1933 and no record of the number was kept, but in the summer of 1934 fasciation seemed more frequent than usual.

DISCUSSION

TEMPERATURE DATA

One of the outstanding results during 1932 was the small daily mean range of 9.21° F between the maximum and minimum temperatures under bagasse as opposed to a range of 17.21° under paper. Inspection of Table 3 shows that the mean minimum temperatures

were approximately equal and that the increased range under paper resulted from higher maximum temperatures, especially during the early part of the year before the plants were large enough to shade the paper materially. On sunny days it became very warm under

TABLE 4.—*Fruit production to age of 30 months.*

Symbol	Treatment	Normal fruits: Number	Normal fruits: Total weight, lbs.	Normal fruits: Average fruit weight, lbs.	Fasciated fruits: Average number per treatment
$A_{1, 2, 3}$	Soil alone	No crop	——	——	No crop
B_1	Paper+300 lbs. N	4,327	16,002	3.70	25
B_2	Paper+600 lbs. N	4,519	19,333	4.28	30
B_3	Paper+600 lbs. N	4,494	19,467	5.45	30
C_1	8 tons bagasse+300 lbs. N	4,462	18,188	4.07	34
C_2	8 tons bagasse+600 lbs. N	4,344	19,770	4.55	42
C_3	8 tons bagasse+600 lbs. N	4,430	20,095	4.54	38
D_1	16 tons bagasse+300 lbs. N	5,098	22,706	4.45	36
D_2	16 tons bagasse+600 lbs. N	4,292	21,009	4.89	42
D_3	16 tons bagasse+600 lbs. N	3,898	18,808	4.82	38
Difference necessary for significance, $P=0.05$				0.31	17

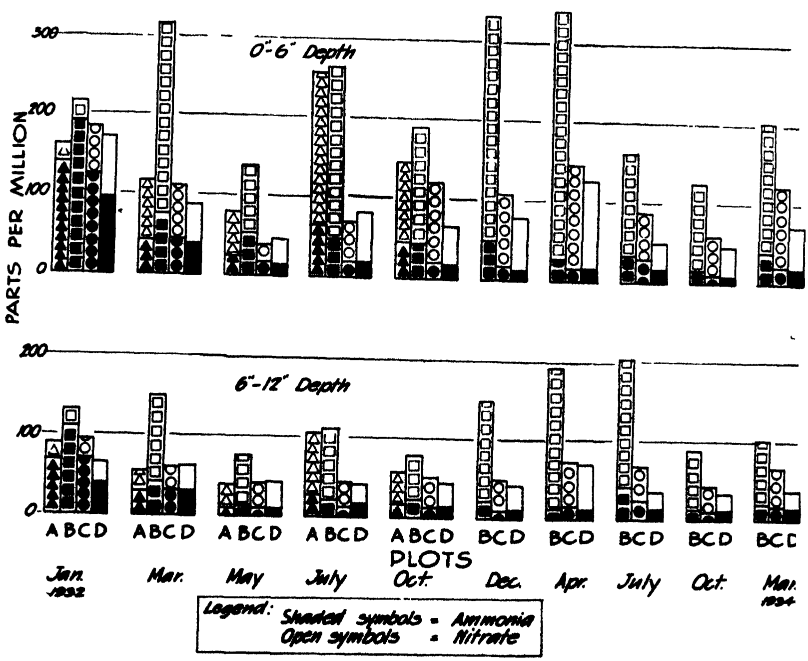

FIG. 2.—Ammonia and nitrate contents of soil under various mulches. The data are given for the 0 to 6 inch depth and 6 to 12 inches, and for various dates. All results are graphed as p. p. m. of nitrogen.

dark paper, and this led to greater variance between days for maximum temperatures under paper than under bagasse. In the latter part of the year with increased shading from plants the variance was diminished.

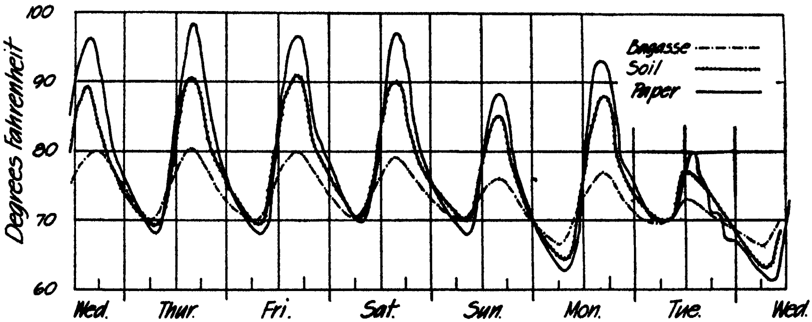

FIG. 3.—A typical week's record of soil temperatures at a depth of 2 inches under various mulches. The record presented is that for the week ending March 2, 1932.

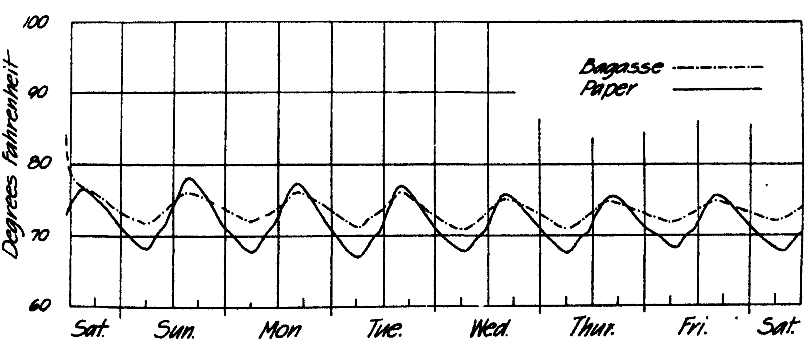

FIG. 4.—A typical week's record of soil temperatures at a later date, week ending June 24, 1933, when plants were bigger and shaded the soil.

The annual range between maximum and minimum temperatures was 15.90° on soil without mulch, which was less than that under paper. Here, too, the variance for maximum temperatures was great, as in the case of paper during the first of the year.

In order to illustrate the daily range in temperature under these soil covers, a week's record ending March 9, 1932, was selected as typical and appears in Fig. 3.

Fig. 4 shows the daily range in soil temperatures under paper and bagasse in the summer of 1933 at a time when the pineapples were large enough to shade the soil area completely.

MOISTURE RELATIONS

A glance at Fig. 1 will show that the moisture contents of the soil at several sampling dates were low in value. Indeed, the moisture contents of all samplings in the A plats, with the exception of the

March 1932 sampling, were so low that plant failure resulted. The soil moisture content at the time of sampling did not indicate for how long a period the moisture contents remained as determined in the sample. Rains and heavy dews might easily have occurred between the sampling periods and masked the true state of affairs. However, when a period of 2 years is considered, the condition of the plants at the end of that time would reflect the integrated effect of the moisture availability and this in turn would reflect the efficiency of the various mulches to conserve moisture at all times.

The low moisture contents obtained in the soil gave rise to the suspicion that these percentages were below the range of water availability and led to the determination of the wilting coefficient and the moisture equivalent. The method of Veihmeyer *et al.* (11) was used for moisture equivalent determination. The wilting coefficient was 18.7 and the moisture equivalent of the soil was found to be 27.9.

At certain times the actual moisture contents were lower than the wilting coefficient and the plants should have suffered from moisture starvation. Most of the plants, on the other hand, gave visual evidence of continued growth, and a check made by digging a trench around a few randomly selected plants, revealed that plant roots had penetrated beyond the sampling depth of 24 inches. The soil in the experimental area was porous and thus permitted plant roots to penetrate even to a depth of 4 feet.

This discovery tended to make useless the interpretation of the moisture results obtained in its relation to plant growth. The data collected, however, do not destroy their usefulness in determining the efficacy of the various mulches to conserve moisture in the soil.

Data from which Fig. 1 was prepared were subjected to statistical methods for ascertaining the effectiveness of various factors on moisture contents, such as effectiveness of (a) mulches, (b) amounts of nitrogen applied, (c) sampling depths, (d) sampling dates, and (e) interactions between these factors. The analysis of variance has been selected to evaluate the magnitude of these factors. The analysis assumes that all treatments have approximately the same standard deviation and that the values for each treatment are adequate samples of a homogeneous, normally distributed population. The analysis of variance is given in Table 5.

TABLE 5.—*Analysis of variance of soil moisture contents.*

Variance due to	Degrees of freedom	Sum of squares	Mean square	F values obtained	F values for significance	
					P=0.05	P=0.01
Total	209	3580.47	—	—	—	—
Mulches	3	391.71	130.57	159.2	2.66	3.90
Sampling dates	9	2805.44	311.72	380.2	1.94	2.51
Depths of sampling	2	203.33	101.67	124.0	3.05	4.73
Amounts of N fertilizer	1	0.06	0.06	13.7	254.32	6366.48
Interactions	17	34.40	2.02	2.5	1.71	2.13
Residual (error)	177	145.53	0.82	—	—	—

The last two columns indicate whether or not the effect of the several factors were significant. The method for testing significance was that of Snedecor (10), and the reader is referred to his article for details.

Reference to the last column indicates that differences in moisture contents between sampling dates, depths, and the kinds of mulches used were highly significant.

SAMPLING DATES

The significant differences in moisture contents between sampling dates were due to the rains that fell. Table 6 records the rainfall for the period of the experiment from November 1931 to October 1934.

TABLE 6.—*Rainfall in inches from Nov. 1931 to Dec. 1934.*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Totals
1931...	—	—	—	—	—	—	—	—	—	—	0.43	1.95	2.38
1932...	1.39	10.40	0.00	0.26	0.00	0.00	0.00	0.00	0.64	0.00	0.00	0.65	13.34
1933...	0.34	3.80	2.17	1.13	0.00	0.00	0.00	0.00	0.00	0.00	1.03	6.77	15.24
1934...	0.62	1.08	0.30	1.10	10.7	0.20	0.42	0.41	0.10	0.00	0.00	0.00	5.30

It is readily seen that the rainfall in December 1931; January and February 1932; February, March, April, November, and December 1933; and February, April, and May 1934 are reflected in the high moisture contents of the soils sampled March 21, 1932; April 11, 1933; and March 16, 1934. Between May and December of the years 1932 and 1933 very little rain fell on the experimental area, and hence the moisture contents of the soils were low during these periods.

MULCHES

While the mean moisture contents of the soil under different mulches varied among themselves within a narrow range, the experimental error was sufficiently small to demonstrate the existence of real differences in moisture contents between them. The mean values are shown in Table 7 accompanied by their standard errors.

TABLE 7.—*Mean percentage of moisture in soil of each mulch treatment, means of all sampling dates, fertilizer levels, and depths.*

Moisture content	Treatments				General mean	Difference for significance	
	No mulch	Paper mulch	8 tons bagasse	16 tons bagasse		P = 0.05	P = 0.01
In per cent....	17.95	20.25	21.24	22.20	20.76	0.42	0.55
In per cent of general mean	86.6	97.6	102.2	107.0	100.0	2.0	2.6

Examination of the values in Table 7 shows that bagasse was distinctly better than paper for conserving moisture, and that paper in turn was distinctly better than plain soil mulch. Without a paper or bagasse mulch the plants failed to grow as shown in Fig. 5.

NITROGEN FERTILIZATION

As expected, the moisture content of the soil was not influenced by use of an increased amount of nitrogenous fertilizer. The mean moisture contents were 20.75 and 20.78%, respectively, for additions of 300 and 600 pounds of nitrogen per acre. The difference necessary for significance was 0.21%.

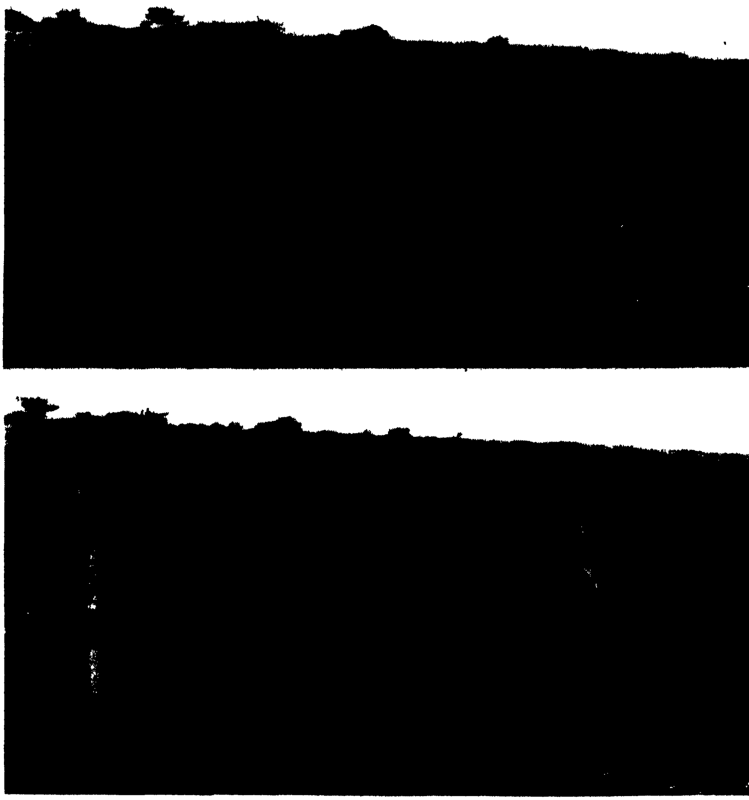

FIG. 5.—Effect of mulch on pineapples.

Above, soil mulch only on left, paper mulch on right. Below, 16 tons bagasse on left, paper mulch on right. Pictures taken Jan. 30, 1933. Pineapples 14 months old.

DEPTH OF SAMPLING

Differences in soil moisture contents at various depths were great, as indicated in Table 8.

This condition is not uncommon. The moisture in the upper layer of soil being closer to the soil surface is either taken up and transpired through plants, or exposed to evaporation through greater air circulation.

TABLE 8.—*Mean moisture content of soil at various depths, means of all sampling dates, fertilizer levels, and mulch treatments.*

Depth in inches	Mean moisture content, %
0–6	19.57
6–12	20.75
12–24	21.98
Necessary for significance	0.30

NITRATES

Reference to Fig. 2 shows the outstanding performance of the paper mulch treatment in maintaining a high nitrate content in the soil. The 8 tons and 16 tons of bagasse treatments appear to have a lower amount of nitrates than even the no-mulch treatment. This demonstrates the long-established finding that an excess of carbohydrate material in the soil brought about by the mixture of bagasse with the soil promotes the development of a high bacterial population which makes use of nearly all the nitrates available in the soil for its growth. Paper mulch by reason of its mode of preparation and its lack of intimate mixture with the soil is not so readily decomposable as is bagasse and hence does not cause the immediate existence of a high carbon-nitrogen ratio in the soil.

With a combined action of maintaining a temperature and retaining moisture content favorable to bacterial growth, the paper mulch serves as a better medium for the increased production of nitrates for plant use.

AMMONIA

The amount of ammonia produced at the beginning of the experiment was high under all mulches, but decreased progressively with time. Evidently the soil was well stocked with bacteria to change the ammonia formed by decomposition into nitrates.

The analysis of variance indicated significant differences in ammonia-nitrogen and nitrate-nitrogen between mulches, depth of sampling, and sampling dates. Through the use of the standard error of the treatments, the analysis showed that paper mulch was better than all other mulches for maintaining a high concentration of nitrates, and that there were no significant differences between nitrate contents due to no-mulch treatment and bagasse at either level. The no-mulch and paper treatments contained significantly larger amounts of ammonia than the bagasse treatments. The top layer of the soil, i. e., 0 to 6 inches, contained significantly greater quantities of ammonia and nitrates than the lower depths.

FRUIT YIELDS

Each plat of the experiment contained 900 plants which is a larger number of plants per plat than is usually necessary to demonstrate a 5% significance in fruit yield between any two treatments (7). Approximately 80% of the possible number of fruits matured and included an unusually large percentage of "hold-overs", fruits which ripen after the normal period.

The standard errors of each treatment for average fruit weight and number of fasciated fruit, respectively, were computed and are indicated in the last row of Table 4.

With the use of the average fruit weight as an index of the efficiency of mulches, Table 4 shows that nitrogen was a limiting factor and that the bagasse treatments produced heavier fruits than the paper treatments. This statement is more clearly borne out when we consider the results presented in Tables 9 and 10.

TABLE 9.—*Average fruit weight in pounds with varying nitrogen fertilization, means of all mulch treatments.*

Mean values	300 lbs. N	600 lbs. N	General mean	Stand. error of diff.	Diff. for sig.	
					P = 0.05	P = 0.01
In pounds	4.09	4.59	4.419	0.08	0.16	0.21
In per cent of general mean	92.5	103.8	100.0	1.74	3.35	4.79

TABLE 10.—*Average fruit weight in pounds for various mulch treatments, means for two nitrogen levels.*

Mean values	Paper	8 tons bagasse	16 tons bagasse	General mean	Stand. error of diff.	Diff. for sig.	
						P = 0.05	P = 0.01
In pounds	4.10	4.41	4.75	4.419	0.09	0.18	0.24
In per cent of general mean	92.8	99.8	107.4	100.0	2.00	4.08	5.50

Odds exceeding 100 to 1 were obtained to indicate that fruit yields due to 600 pounds of nitrogen per acre were higher than those due to 300 pounds of nitrogen per acre; that 8 tons of bagasse and 16 tons of bagasse treatments produced significantly higher yields than paper mulch treatment; odds exceeding 100 to 1 were obtained to indicate that 16 tons bagasse treatment produced higher fruit yields than 8 tons bagasse treatment.

A note is inserted here to call attention to the fact that at the installation of the experiment bagasse was laid between the beds of the paper plats as well as between the beds of the bagasse plats. No doubt this bagasse covering has helped the paper-treated plats to make a good showing. Also, it was found by analysis that the amount of soluble iron in the leachate of bagasse was considerably more than amounts of iron occurring naturally in the soil solution. It is possible then that the plants in bagasse-treated plats may have obtained some additional iron and thereby permitted the plants to perform better in these plats than those grown in plats covered with other forms of mulches. However, more information was necessary to establish the probability that iron was a limiting factor.

SUMMARY

A six replication experiment of nine treatments was installed to compare bagasse as a mulch against paper mulch and no mulch for pineapples.

Data of 2 years' continuous records of soil temperatures under the mulches, of soil moistures, nitrates, and ammonia determined periodically, and of pineapple fruit yields obtained at harvest time were used to measure the efficiencies of the various mulches. The following conclusions have been reached:

1. The annual mean range between the maximum and minimum temperatures was one-half as great under bagasse as under paper; that for the no-mulch plats being less than that under paper.
2. Soil moistures were highest in bagasse-treated plats, followed by papered and no-mulch plats.
3. The first 6 inches of soil contained significantly less moisture but more nitrate than soil at greater depths.
4. Nitrate content of the soil was greater in paper treatment than in the bagasse treatment or soil alone.
5. Fruit yields were highest in bagasse-treated plats.
6. Lack of sufficient nitrogen was a limiting factor for maximum fruit production.

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FURTHER WORK WITH THE CUNNINGHAMELLA PLAQUE METHOD OF MEASURING AVAILABLE PHOSPHORUS IN SOIL[1]

A. MEHLICH, E. B. FRED, AND E. TRUOG[2]

FOLLOWING the first report (5)[3] on the Cunninghamella plaque method of measuring available phosphorus in soil, additional investigations were made in an attempt to improve the test and study its application. This report gives some of the results of these investigations, including a description of a new culture dish, comparisons of results with field tests comprising a variety of soil types and crops, and a comparison of results with Neubauer's seedling method.

THE NEW CULTURE DISH

In the test with the soil placed in small petri dishes, the maintenance of a uniform moisture content of the soil during incubation was difficult; the accurate measurement of the diameter of fungus growth was interfered with by the development of the natural fungus flora, especially when incubated for more than 48 hours; and more soil than is always desirable was required for making tests. After various trials, a new type of clay culture dish was designed which overcame these shortcomings to a large degree. This special dish[4] (Fig. 1) consists of a clay slab (55 mm in diameter by 15 mm thick) having a cavity (23 mm in diameter by 7 mm deep). The surface of the cavity is glazed so as to be waterproof, but the rest of the slab is unglazed and has a porosity of 8 to 10% so that it will hold moisture and thus promote the growth of the fungus uniformly over its surface. The surface of the unglazed portion of the dish is of dark color, such as dark red, in order that it may serve as a good background against which the white mycelium may be easily seen.

NOTES ON PROCEDURE

The procedure still followed for testing the phosphorus needs of soils is much the same as previously described (5), except that with the new type of culture dish only one-fifth as much soil and nutrient solution is needed. For the most satisfactory results, experience has shown that the following points should be observed:

Fungus cultures.—Reserve stocks, carried on malt extract-agar slants (2.5% malt extract, 2% agar), should be transferred every 4 months and kept in a cool place (2). The spore suspensions for inoculation are prepared from fresh malt

[1]Contribution from the Departments of Agricultural Bacteriology and Soils, University of Wisconsin, Madison, Wis. This investigation was supported in part by a grant from the Wisconsin Alumni Research Foundation. Received for publication July 29, 1935.

[2]Research Assistant and Professors of Agricultural Bacteriology and Soils, respectively. The authors are indebted to a number of investigators at various agricultural experiment stations for supplying many of the soil samples used in these studies.

[3]Figures in parenthesis refer to "Literature Cited," p. 831.

[4]This special dish may be purchased of the Coors Porcelain Company, Golden, Colorado.

extract-agar slant cultures. The age of these cultures should be at least 1 week and not more than 4 weeks.

Plaque preparation.—The amount of nutrient solution needed varies with the soil; an excess should be avoided, the optimum being the point at which the soil particles just adhere to each other. The soil, well mixed with the nutrient solution, is packed into the cavity of the dish with a spatula, the surface smoothed and pressed just slightly below the rim of the cavity. Care should be taken not to smear soil over the unglazed surface. The use of dry culture dishes helps in this respect. The pan in which the dishes or plaques are placed should be adequately supplied with water, that is, filled to a depth of 6 to 8 mm.

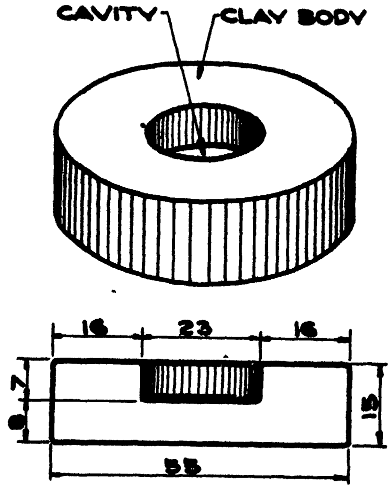

FIG. 1.—New culture dish.

Period of incubation.—For peats and mucks, incubation should be extended from the usual 48 hours to 72 hours, because some of the available phosphorus in organic form is not fully utilized in 48 hours.

Making readings.—A pair of calipers is useful in measuring the diameter of the growth. Several readings should be made and measurements should include only the main or actual body of the growth, ignoring a few individual hyphae which project beyond the main mass.

Calcareous soils.—If *C. blakesleeana* is used instead of *C. elegans*, calcareous soils need not be neutralized. However, if this is done, the growth indicating adequacy of phosphate is changed from a 22 mm diameter to a 16 mm diameter.

COMPARISON OF RESULTS WITH FIELD TESTS

Using the special clay dishes and *C. blakesleeana* minus strain, we made tests on soils which had received different phosphorus treatments in the field and for which the yields of different crops were available. The soils were obtained from widely different localities in the United States and from Rothamsted, England. The majority of these soils had been under observation in the field for many years. The crop yields and fertilizer treatments were taken from station reports (1, 3, 4, 6, 7, 8, 9, 11), or the information was privately communicated. The results given in Table 1 represent only a portion of the tests made.

In general, the results indicate that phosphorus fertilization is beneficial when the available phosphorus supply produces a fungus growth of less than 22 mm in diameter. At a growth of 22 to 24 mm in diameter, apparently the yields of small grains, corn, grasses, and potatoes are no longer benefited by phosphorus applications. The *Leguminosae* and the root crops are also benefited by application of phosphorus if the soil in which they are to be grown supports a fungus

TABLE 1.—*Growth of Cunninghamella and crop yields on phosphated and non-phosphated soils and results with chemical method.*

Kind of soil	Amount of readily available phosphorus, Truog chemical method, p.p.m.		Diameter of lateral growth of *Cunninghamella*, mm		Crop yields and increases per acre on treated and untreated fields					
	Non-phosphated	Phosphated	Non-phosphated	Phosphated	Non-phosphated	Phosphated	Increase	Non-phosphated	Phosphated	Increase
						Corn, bu.			Oats, bu.	
Volusia silt loam	10	24	7	24	14.0	22.0	8.0	11.0	15.0	4.0
Hagerstown silt loam	18	40	11	24	19.1	35.8	16.7	26.3	34.5	8.2
Muscatine silt loam	18	215	14	35	36.0	59.0	23.0	34.0	48.0	14.0
					22.0	37.0	15.0	28.0	44.0	16.0
						Wheat, bu.			Clover, tons	
Wooster silt loam	8	14	10	20	8.0	18.0	10.0	0.6	1.0	0.4
Miami silt loam	4	15	12	28	11.0	19.0	8.0	0.9	1.3	0.4
Broadbalk field	27	235	12	34	12.0	21.0	9.0		Barley, bu.	
Stockyard field	19	66	16	46	10.0	16.0	6.0	11.0	16.0	5.0
Stockyard field	20	64	18	44		Alfalfa, tons				
Miami silt loam	18	32	25	38	3.5	3.8	0.3	—	Beets, tons	
						Soybeans		5.1	25.6	20.5
					3.4	6.7	3.3			
						Carrots			Cabbage	
Merrimac silt loam	21	90	16	50	11.6	14.6	3.0	1.0	7.1	6.1
						Tomatoes			Potatoes, bu.	
					7.9	9.8	1.9	244.0	305.0	61.0
					Various garden crops					
						Early varieties*			Late varieties, tons†	
Silt loam	60	88	23	45	4.0	6.0	2.0	5.7	10.7	5.0
						Potatoes, bu.			Onions, bu.	
Peat (old)	30	72	17	41	280.0	400.0	120.0	10.8	22.5	11.7
Peat (new)	25	58	12	30	210.0	380.0	170.0	8.4	21.3	12.9
Muck (old)	96	230	28	42	—	—	—	15.9	16.3	0.4
Muck (new)	50	205	15	42	—	—	—	18.1	19.3	1.2

*Peas, beets, green beans, leaf lettuce.

†Spinach, cauliflower, pepper, carrots.

growth of 26 to 28 mm in diameter; and most garden crops benefit from phosphorus if the soil supports a fungus growth of 30 mm or less in diameter. No crop was found to respond to phosphorus fertilization if the soil in which it was grown permitted a growth of more than 36 mm in diameter.

As previously shown, $CaCO_3$ influences the availability of phosphorus, and hence the growth of the fungus. To overcome this influence, it was recommended that the soil be neutralized with citric acid. This is objectionable in that the natural soil conditions are changed, and in addition it is not always possible to neutralize the soil within certain prescribed limits.

It has been noted that *C. blakesleeana* showed considerably better growth on calcareous soils than *C. elegans*. Using the former fungus, we tested a number of soils containing different amounts of $CaCO_3$ and showing a variation of response to phosphorus fertilization in the field. The results, given in Table 2, show evidence that *C. blakesleeana* may be successfully employed in testing calcareous soils without pre-treatment with acid. From these results the general inference can be made that a phosphorus need is indicated when the diameter of growth is less than 16 mm. This will vary somewhat with the plant grown. Alfalfa, especially, when grown on soils with a fertile subsoil, may not suffer for lack of phosphorus even in case the growth of *Cunninghamella* is only 13 to 14 mm in diameter.

COMPARISON OF RESULTS WITH THOSE OF NEUBAUER'S METHOD

In Table 3 results are given comparing *Cunninghamella* and Neubauer values[5] on 40 soils which differ greatly in reaction, texture, and phosphorus supply. For soils having Neubauer values above 5 mgm of P_2O_5 per 100 grams of soil, which according to Neubauer is approximately the border line dividing soils that need phosphorus fertilization from those that do not, depending, however, somewhat on the crop grown, the diameter values of *Cunninghamella* are greater than 25 mm. In the case of the lower Neubauer values, the growth of the fungus is also small. Between these extremes the agreement is more variable. Results of Truog's chemical method (10) show, in general, good agreement with both biological tests.

SUMMARY

A special clay culture dish has been designed for conducting the *Cunninghamella* test for available phosphorus of soils. This dish has the advantage of being more durable than the small glass petri dish, and its use makes the results more accurate and satisfactory. This dish was used in testing a great variety of soils, and the results obtained agree quite satisfactorily with crop yields in the field and with the results of the Neubauer and chemical methods.

[5]Neubauer values furnished by S. F. Thornton of Purdue University.

TABLE 2.—*Growth of Cunninghamella and crop yields on phosphated and non-phosphated calcareous soils and results with chemical method.*

Soil No.	Calcium carbonate content	Amount readily available phosphorus Truog chemical method		Diameter of lateral growth of *Cunninghamella*		Crop yields and increases per acre on treated and untreated fields		
		Non-phosphated	Phosphated	Non-phosphated	Phosphated	Non-phosphated	Phosphated	Increase
	per cent	p.p.m.	p.p.m.	mm.	mm.	tons	tons	tons
							Alfalfa	
247	3.85	15	56	12	20	1.2	1.9	0.7
251	2.31	110	150	14	28	1.2	1.8	0.6
253	8.67	74	80	9	17	1.3	2.3	1.0
255	6.12	37	47	7	19	2.3	4.4	2.1
113	2.03	26	—	15	23	5.0	5.0	0.0
							Beets	
330	6.80	135	150	12	21	12.6	14.6	2.0
325	2.50	130	170	12	21	11.6	25.0	13.4
328	7.70	24	49	14	22	12.8	16.8	4.0
327	3.50	150	187	29	37	16.8	17.0	0.2
121	3.77	62	—	27	32	23.0	23.0	0.0
							Wheat	
						bu.	bu.	bu.
329	1.50	100	141	17	20	35.0	35.0	0.0
							Barley	
324	0.34	160	178	31	38	55.0	55.0	0.0
326	20.00	15	21	7	12	32.0	63.0	31.0
							Sweet Clover	
						Straw-Seed pounds	Straw-Seed pounds	Straw-Seed pounds
249	37.66	8	12	7	11	1180– 172	4880– 750	3700–578

TABLE 3.—*Level of readily available phosphorus of 40 soils as revealed by Cunninghamella, Neubauer, and chemical tests.*

Soil No.*	pH	Available phosphorus		*Cunninghamella* method, diameter of lateral growth, mm
		Truog chemical method, p.p.m.	Neubauer method, mgm P_2O_5 per 100 grams soil	
430	5.5	17	0.0	5
1752	5.7	8	0.7	8
1798	6.0	5	0.8	8
1740	4.3	8	1.0	12
1589	5.9	80	1.4	14
1640	5.7	36	1.6	12
1753	5.5	9	1.7	11
1844	4.7	7	1.8	11
1738	4.4	18	1.9	15
1739	4.0	9	2.0	14
211	7.5	20	2.1	8
1636	5.7	17	2.2	13
1643	5.6	16	2.3	16
1648 M	7.3	68	2.4	16
1644	5.7	14	2.6	15
1635	5.2	14	2.7	13
1756 M	6.2	19	2.9	10
1737	4.5	24	3.0	15
1632	4.7	10	3.3	15
1849	7.8	27	3.5	17
1638	5.9	84	3.6	21
1650 M	7.6	19	3.7	14
1588 P	6.9	32	4.0	16
1645	5.9	38	4.1	21
1846	7.6	162	4.2	16
1847	7.7	122	4.3	15
1845	6.8	34	4.5	17
1631	5.3	29	4.8	23
1593 M	5.4	155	5 0	28
1590 P	5.6	75	5.5	49
1637	5.8	88	6.1	29
1576 M	5.6	76	6.4	34
1586 P	5.5	170	6.5	50
1848	7.8	55	10.5	31
1582 P	6.1	115	10.7	53
212	5.7	92	11.0	46
1584 P	6.2	113	11.9	51
1592 P	5.2	79	12.2	44
1850	6.7	150	14.3	45
1580 P	6.4	180	15.0	54

*M = Muck. P = Peat.

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IMMEDIATE EFFECTS OF FERTILIZATION UPON SOIL REACTION[1]

C. B. Clevenger and L. G. Willis[2]

It has long been observed that some fertilizer materials, after a period of continual use, have a marked effect upon the reaction of the soil. Ammonium sulfate ultimately increases the soil acidity, while sodium nitrate has the reverse effect. According to Pierre (1),[3] the organic ammoniates are acidifying agents, but Plummer (2) has reported results showing an alkaline effect of dried blood after several years of use. A change in soil reaction is often not desirable and especially so when the reaction already approaches that which under the prevailing soil and climatic conditions seems best for the production of the crop that is to be grown.

Due to the increased manufacture and use of ammonium salts during the last 25 years much attention has recently been given by various investigators to the acid- or base-forming properties of fertilizers. The work of Pierre (1) in formulating a laboratory method for the determination of the acid- or base-forming property of fertilizers has provided a means whereby these properties can be expressed quantitatively in terms of calcium carbonate equivalent. Manufacturers are now enabled to place on the market fertilizers which are non-acid-forming by the substitution of the proper amounts of basic materials for a part of the filler.

Pierre's factors relate only to the ultimate effects upon soil reaction. While these are important, intermediate effects also should be considered. In the case of organic ammoniates there is evidence that in the process of ammonification intermediate alkaline effects of significance may be produced. Since the reaction of the soil, or factors associated with it, is often of prime importance in the production of crops, it seems reasonable to believe that temporary or intermediate effects of fertilizers upon the reaction of the soil may play a greater part in the plant-soil relationship than at present suspected.

ALKALINITY PRODUCED BY AMMONIFICATION

Willis and Rankin (5) have shown that organic forms of nitrogen become converted into ammonia so rapidly in the soil as to produce injury on cotton seedlings. In some later work,[4] a measure of the amount of this conversion was obtained by placing ammonifying cultures within closed containers which were held at constant temperature and pressure. With 300 milligrams of nitrogen in the form of

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[3]Figures in parenthesis refer to "Literature Cited," p. 846.

[4]Unpublished data presented at the meeting of Section O, A. A. A. S., Atlantic City, N. J., 1932, by L. G. Willis.

cottonseed meal in a medium of Norfolk sand, ammonia formation was rapid throughout a period of 16 days during which time nearly half of the total nitrogen of the cottonseed meal was ammonified. The conversion was accelerated by the addition of calcium sulfate to the cultures (Fig. 1).

The pH of the cultures increased rapidly reaching a constant value in 8 days. In the cultures without calcium sulfate the maximum pH

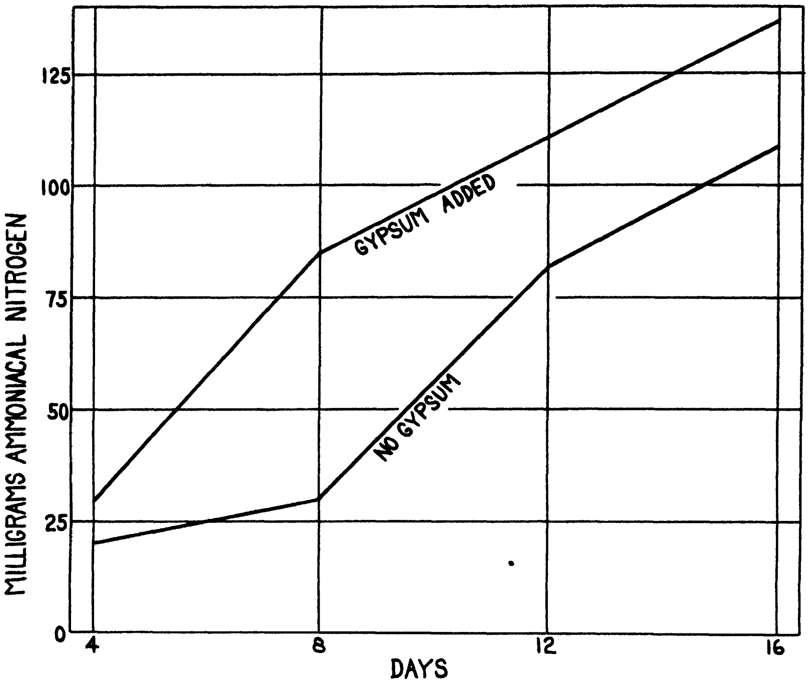

FIG. 1.

was about 8.5, whereas with calcium sulfate the maximum was about 8.0 (Fig. 2). Determinable amount of ammonia were found in the atmosphere above the cultures, the concentration being greatest where the calcium sulfate was omitted (Fig. 3).

EFFICIENCY OF ORGANIC AMMONIATES

The rapid attainment of these alkaline values suggested the possibility that, while organic ammoniates are ultimately acid forming, there might be an initial neutralizing effect of appreciable magnitude due to formation of ammonia soon after the fertilizer containing these materials was applied to the soil.

If such an effect was evident, a question might be raised as to the significance of this property of the organic ammoniates as they are commonly used in fertilizers. It has long been considered that the value of organic materials lies in the fact that they provide a source of nitrogen that becomes available slowly throughout the season of crop growth.

The validity of this opinion is subject to considerable doubt in view of the evidence of rapid conversion of organic nitrogen into ammonia.

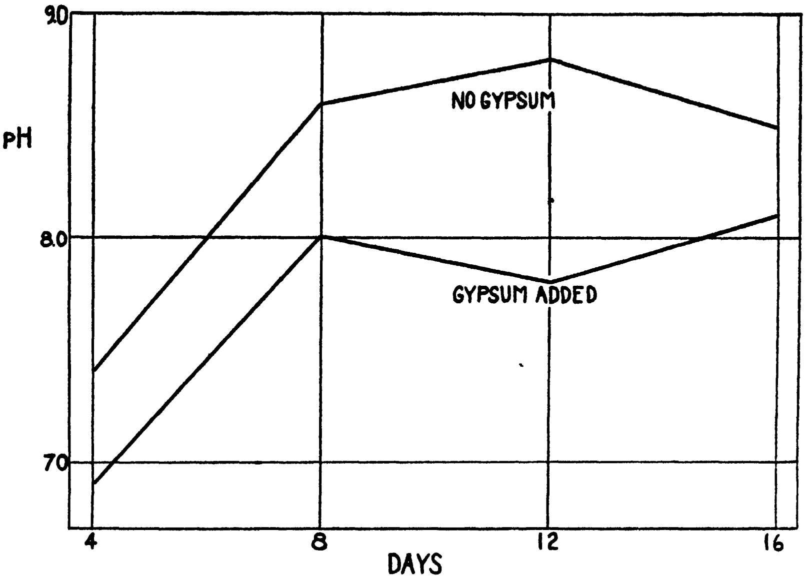

FIG. 2.

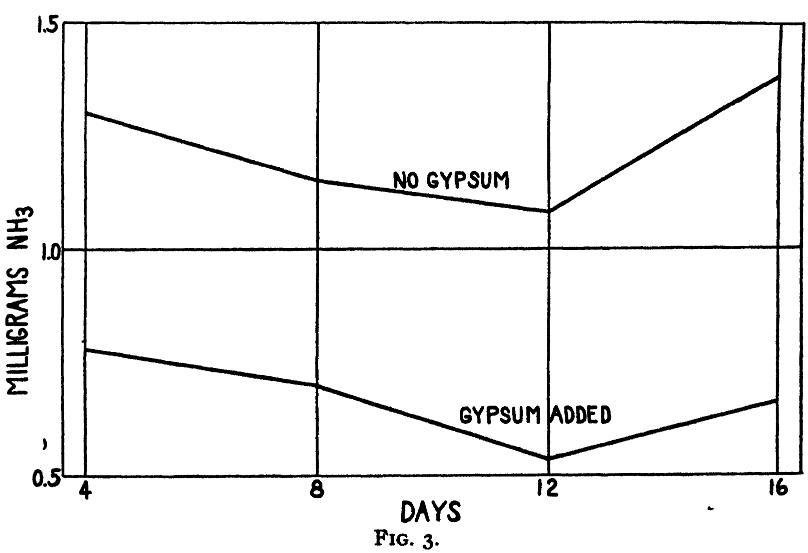

FIG. 3.

The object of the work to be presented here is to determine the magnitude of the early neutralizing effect of the organic ammoniates, cottonseed meal and urea, in comparison to that of dolomitic limestone used at rates calculated to produce a non-acid-forming fertilizer.

PLAN AND PROCEDURE OF THE WORK

Complete fertilizers of various formulas were mixed in potted soils, kept at a constant temperature of 25°C and moisture content of 50% of the saturation capacity, and the trends of the soil reaction were followed by making pH determination of the soil at frequent intervals. The quinhydrone electrode was used for the determination of the pH values immediately after the fertilizers were mixed with the soil and thereafter during a period of 4 to 5 weeks following the fertilizer applications.

Four different soils were used, a Coxville fine sandy loam and a Norfolk sandy loam from the Coastal Plain, the former being well buffered with organic colloids, and Durham and Cecil sandy loams from the Piedmont area, of which the latter was moderately buffered with mineral colloids. The soils were used as they came from the field without preliminary drying, their pH values ranging from 4.3 to 5.3. They were also limed with C. P. precipitated calcium carbonate in amounts intended to raise their pH values to between 6.0 and 7.0. Reaction trends from the same fertilizer treatments were thus obtainable for each of the soils in two different pH ranges.

The respective soils in amounts ranging from 6 to 8 pounds were put into 1-gallon glazed earthernware pots which were placed into a humified constant temperature insulated box in which air was circulated by a forced draft. All the soils both without and with added lime were kept in the constant temperature box for a week before the additions of fertilizer in order for a chemical and biological equilibrium to be established.

The fertilizer-soil mixtures were made with a ratio of 1:0.008. This is calculated from the assumption that the fertilizer would be applied at the rate of 1,000 pounds per acre, drilled in rows 6 inches wide and 4 feet apart, and the fertilizer mixed with one-half of the depth of the surface soil.

The analysis of all the fertilizers used was 3% nitrogen (N), 8% available phosphoric acid (P_2O_5), and 6% potash (K_2O). The formulas differed only in respect of the source of nitrogen. In each the potash all came from muriate of potash (51.2% K_2O) and the phosphoric acid all came from superphosphate (15.4% P_2O_5). The nitrogen came from ammonium sulfate (20.5% N), sodium nitrate (16.2% N), cottonseed meal (6.19% N), and urea (46.3% N).

The formula in which ammonium sulfate was used as the sole source of nitrogen was designated as the standard. Each of the other forms of nitrogen, sodium nitrate, cottonseed meal, and urea, were substituted for one-fourth, one-half, three-tourths, or all of the ammonium sulfate, respectively.

The substitution of the variant forms of nitrogen made 13 different formulas and all were applied to the four soils, both limed and unlimed, without and with supplements of dolomitic limestone in amounts calculated to produce a non-acid fertilizer. An outline of the fertilizer treatments is given in Table 1. Duplicate treatments were not made.

In sampling the pots for the determination of the pH of the soil, two cores of soil extending from the top to the bottom of the pot were withdrawn, mixed, and a sample taken. The remainder was returned to the pot. In maintaining the soil at the proper moisture content the weight of soil withdrawn for samples was deducted from the previous total weight. Check pots in which the soil received no addition of fertilizers were included in each series. No plants were grown in this work.

TABLE 1.—*Sources of nitrogen in fertilizer treatments.*

Formula Nos.	Source of nitrogen in fertilizer formula	
1	————	All from ammonium sulfate
2	¼ from sodium nitrate	¾ from ammonium sulfate
3	½ from sodium nitrate	½ from ammonium sulfate
4*	¾ from sodium nitrate	¼ from ammonium sulfate
5*	All from sodium nitrate	————
6	¼ from cottonseed meal	¾ from ammonium sulfate
7	½ from cottonseed meal	½ from ammonium sulfate
8	¾ from cottonseed meal	¼ from ammonium sulfate
9	All from cottonseed meal	————
10	¼ from urea	¾ from ammonium sulfate
11	½ from urea	½ from ammonium sulfate
12	¾ from urea	¼ from ammonium sulfate
13	All from urea	————
Check	Unfertilized	

*Formulas 4 and 5 are potentially alkaline and therefore did not require a supplement of dolomitic limestone.

RESULTS

The reaction trends from the different fertilizers are shown in Figs. 4 to 7. The broken line and solid line curves represent, respectively, the reaction trends with the fertilizers, without and with the dolomite supplements. The dotted lines are the curves for the untreated soils used as checks.

INITIAL DECREASE IN PH VALUES

In all cases, on mixing the fertilizers with the soil, a drop in the pH of the soil ranging from 0.6 to over 1.0 unit took place immediately. The opinion that this was primarily a salt effect was verified later when similar results were obtained from additions of superphosphate and muriate of potash to the soils in amounts equivalent to those contained in the fertilizer.

In the limed soils the initial decrease in pH was greater than that found in the unlimed soils excepting the Coxville soil in which the difference was negligible.

On the less well buffered soils of the Durham and Norfolk series without lime or fertilizer there was an unexplained trend toward lower pH values throughout the experiment. Where lime was added this trend was distinctly evident on the Cecil soil, very pronounced on the Norfolk and Durham soils, and not perceptible on the Coxville. All pH changes in the soil-fertilizer mixtures, therefore, are to be interpreted relative to those of the soil alone.

Following the initial decrease in pH due to the addition of fertilizer without the dolomite supplement, there is a slight but definite increase with formula 1 except in the Coxville soil. In the Norfolk and Durham soils this trend persists throughout the course of the experiment. In the limed soils the rise in pH is not so pronounced after the first few days.

The effect of sodium nitrate is virtually identical with that of ammonium sulfate in all soils both without and with lime. It appears, therefore, that under the conditions of this experiment and within

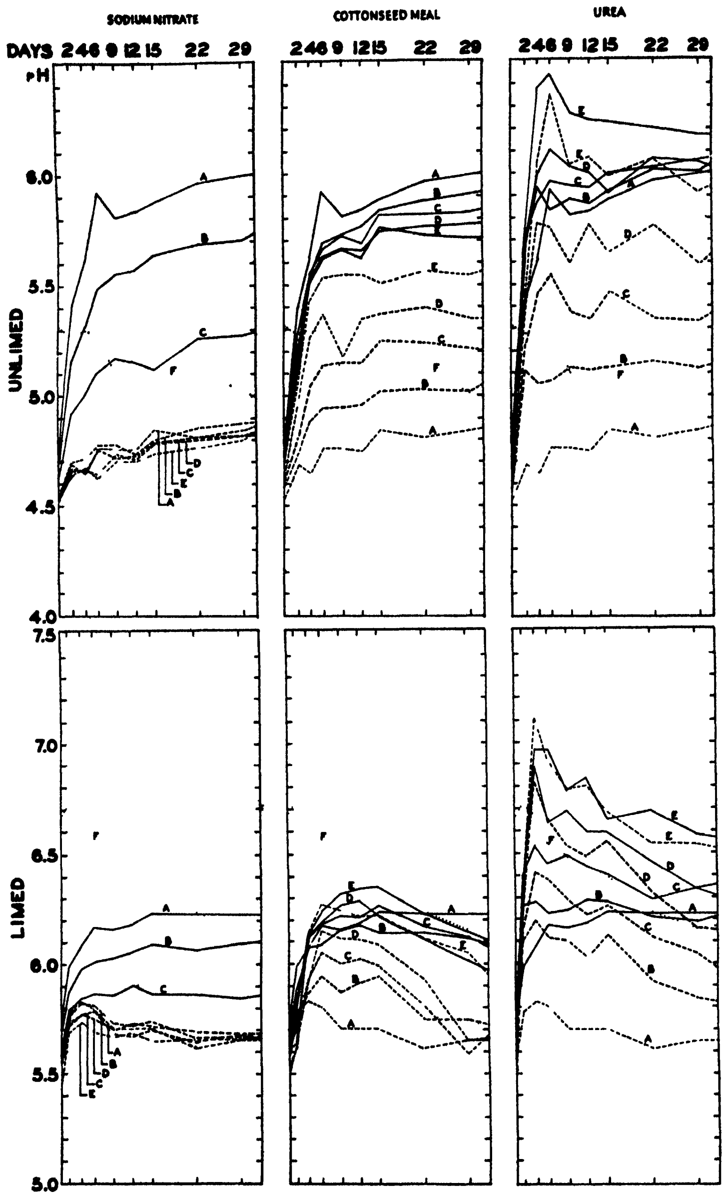

FIG. 4.—Durham sandy loam.

Broken lines, fertilizers without dolomitic limestone; solid lines, fertilizers supplemented with dolomitic limestone; dotted lines, unfertilized or check. Curves, A, all ammonium sulfate; B, three-fourths ammonium sulfate; C, one-half ammonium sulfate; D, one-fourth ammonium sulfate; E, no ammonium sulfate; and F, check.

a period of 30 days any acidity or alkalinity that might develop from these two materials must depend upon the utilization by plants of anionic or cationic nitrogen from the two compounds.

INCREASES IN pH VALUES WITH DOLOMITE SUPPLEMENTS

In the fertilizers containing ammonium sulfate and sodium nitrate with dolomitic limestone supplements, there was a rapid increase in pH reaching a virtual maximum at 10 to 15 days and thereafter a more gradual rise relative to the unfertilized soils. The extent of the rise was proportional to the amount of dolomite or to the amount of ammonium sulfate. It is doubtful that there is any significance in the latter relationship, however, since the salt concentration was maintained by the sodium nitrate which was substituted for the ammonium sulfate and these mixtures had virtually identical effects when used without the dolomite.

EFFECT OF COTTONSEED MEAL ON pH

When cottonseed meal was substituted for ammonium sulfate in the unlimed soils there was an extremely rapid increase in pH during the first 3 days followed by a further slow increase for the entire period relative to the unfertilized soil. Without the dolomite the increase in pH was proportional to the amount of cottonseed meal used, each successive increment producing an increase of 0.1 to 0.2 pH.

In the less well buffered soils without lime the order of the relation between the content of cottonseed meal and pH increase is generally reversed with the fertilizers having dolomitic supplements, indicating a somewhat greater neutralizing value for the dolomite supplement than for the ammonia produced by ammonification. There was little difference in the trends of the two types of fertilizer during the whole period except for greater pH values in those with the dolomite supplements, with which a lesser difference due to the form of nitrogen used was noted.

NEUTRALIZING EFFECT OF UREA

All effects noted with urea in the fertilizers were similar to those of the corresponding cottonseed meal formula, but more pronounced, with the exception that the ammonia formed from urea was a more active neutralizing agent than was the dolomite supplement. Maximum pH values were reached more promptly with the urea. In the Cecil soil this was accomplished within 24 hours when all the nitrogen was supplied as urea. In the fertilizers without dolomite supplements a greater pH range was found than with the cottonseed meal, whereas, with the dolomite supplement the range with the urea was less.

TRENDS IN LIMED SOILS

Relative to the pH values of unfertilized soil, none of the fertilizer formulas gave evidence of as great a neutralizing effect in the limed soil as was found in the corresponding soil unlimed, nor was the range of pH values produced by the organic ammoniates without dolomite as great in the limed soils as in those without lime.

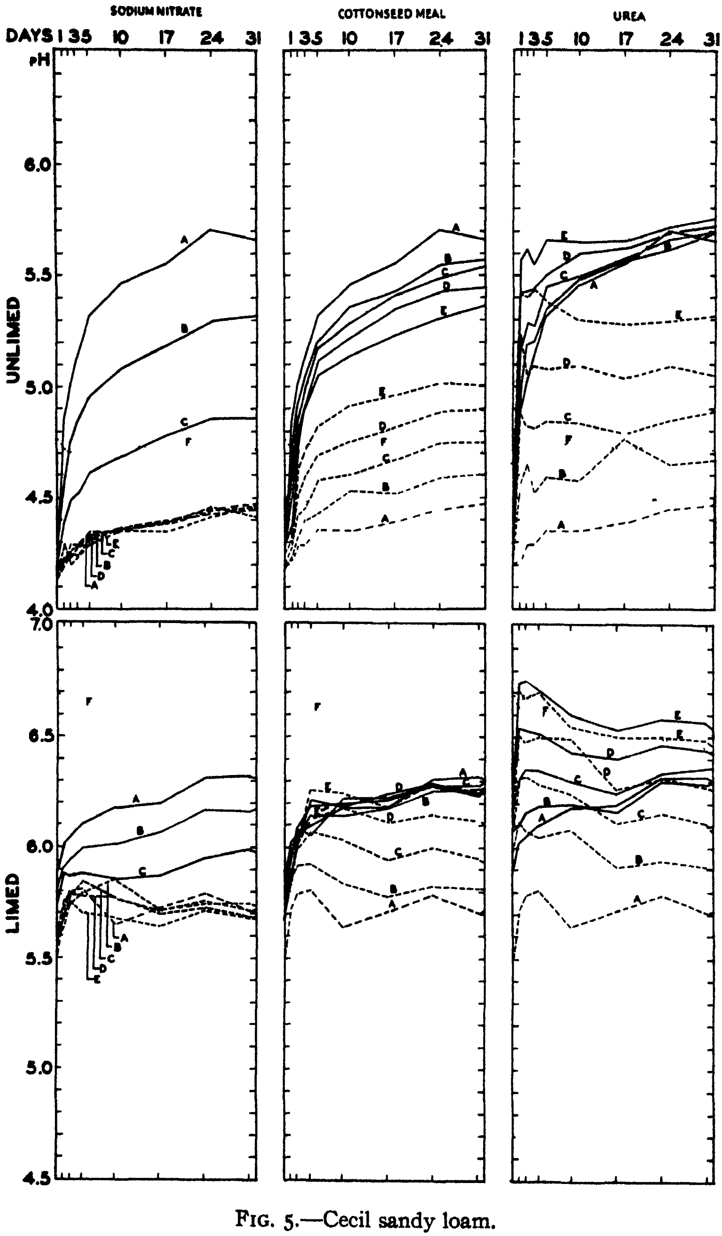

FIG. 5.—Cecil sandy loam.

Broken lines, fertilizers without dolomitic limestone; solid lines, fertilizers supplemented with dolomitic limestone; dotted lines, unfertilized or check. Curves, A, all ammonium sulfate; B, three-fourths ammonium sulfate; C, one-half ammonium sulfate; D, one-fourth ammonium sulfate; E, no ammonium sulfate; F, check.

As was found in the unlimed soils, the fertilizers containing ammonium sulfate and sodium nitrate were virtually identical in their effect on the pH values when no dolomite supplement was included. With the dolomite, however, there was a sharp initial increase in pH followed by a slowly rising trend. With the organic ammoniates, however, both without and with the dolomite supplements there was a pronounced tendency to a decrease in pH after the early rise. This downward drift was proportional to the amount of organic ammoniate in the formula and more pronounced with urea than with cottonseed meal.

In the Coxville soil no fertilizer formula gave a pH greater than that of the unfertilized soil. In the other soils without added lime all fertilizers with dolomite supplements and all fertilizers with one-half or more of the nitrogen from the organic forms gave greater pH values than those of the respective unfertilized soils. In the limed soils the neutralizing value of the dolomite supplements was less pronounced, cottonseed meal raised the pH above that of the unfertilized soil only on the Norfolk sandy loam, and urea gave a distinct increase in pH over that of the unfertilized soil only on the poorly buffered Norfolk and Durham sandy loams.

RELATIVE NEUTRALIZING EFFECTS OF COTTONSEED MEAL AND UREA

An interesting comparison between cottonseed meal and urea is shown in the results on all but the Coxville soils where the pH differences are too small to be considered significant. In the unlimed soils the virtual maximum pH value reached by the fertilizers containing all the nitrogen as cottonseed meal without dolomite was attained in 5 to 7 days and was approximately the same as that found in the corresponding treatments where urea was the source of one-half of the nitrogen. The urea, however, gave maximum pH values in 1 to 6 days. From the trend of the curves of the urea formulas it appears that all the nitrogen of this compound had been converted to ammonia within these periods. It would seem, therefore, that within a week under the conditions of this experiment one-half of the cottonseed meal had been converted into ammonia.

AMMONIFICATION OF UREA

It would be expected that urea in its original form would be readily leached from the soil. The actual risk of loss by this means is negligible, however, in view of the evidence of an extremely rapid conversion to ammonia in the soil.

It was impossible to determine the course of ammonification and nitrification in these soils but, at the expiration of the work, nitrates were determined. In only a few random cases was there any evidence of the nitrification of materials added in the fertilizers. No explanation can be offered, therefore, for the gradual decreases in the pH values of the unfertilized Norfolk and Durham soils, nor for the almost parallel decreases with the fertilizers containing cottonseed meal and urea in these soils when limed.

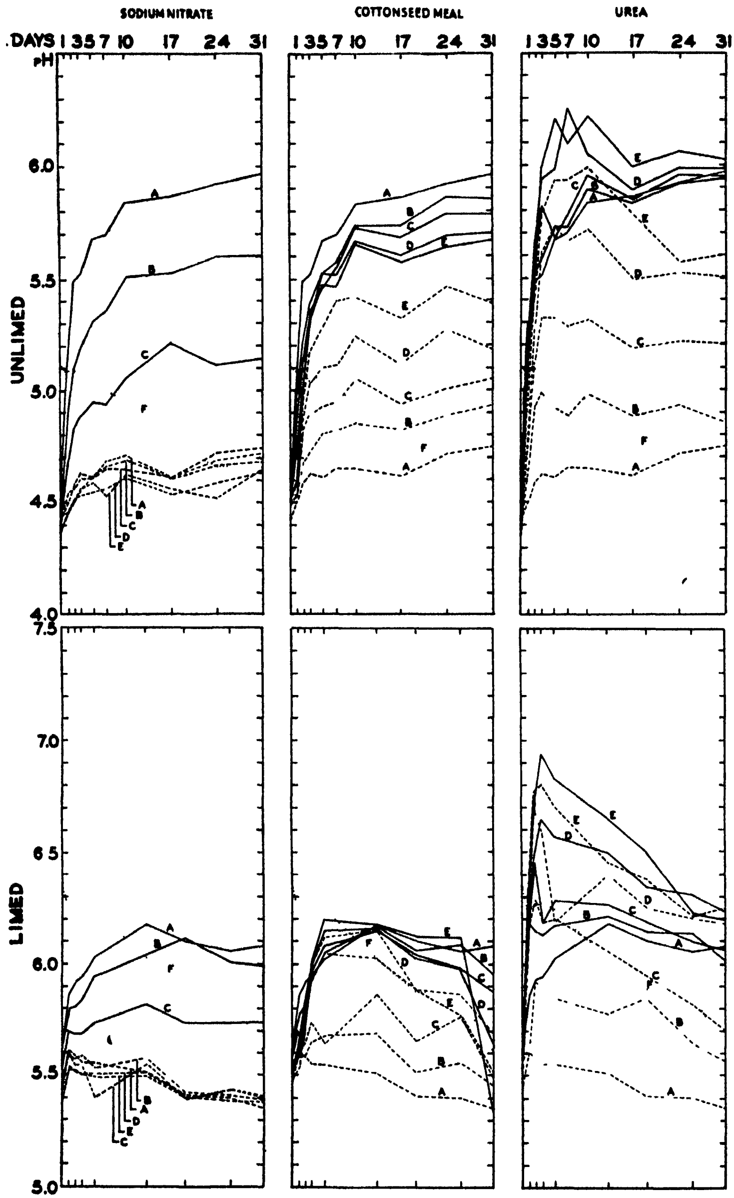

FIG. 6.—Norfolk sandy loam.

Broken lines, fertilizers without dolomitic limestone; solid lines, fertilizers supplemented with dolomitic limestone; dotted lines, unfertilized or check. Curves, A, all ammonium sulfate; B, three-fourths ammonium sulfate; C, one-half ammonium sulfate; D, one-fourth ammonium sulfate; E, no ammonium sulfate; F, check.

APPLICABILITY OF RESULTS

It is evident that within a month after the application of fertilizers the organic ammoniates can serve as neutralizing agents almost as extensively as can a dolomite supplement. The physiological effects of the two methods of neutralization are not equivalent however. Tiedjens and Robins (3) have shown that ammonium nitrogen is most available at the higher pH levels. From a nutritive standpoint, therefore, it would make little difference whether the pH was reached by the use of a lime supplement to the fertilizer or by the ammonification of the organic materials.

It should be understood that these results were obtained at a constant soil temperature of 25°C. This condition was imposed by the facilities available. At other temperatures the rates of ammonification and of reaction of the dolomite supplement would differ from those observed in this work. The salt effect on pH would probably be influenced to a negligible degree by temperature.

In soils at lower temperatures than 25°C, therefore, the natural organic forms of nitrogen would have a lesser rate of neutralization of soil acidity and would act as slowly available sources of nitrogen. The rate of neutralization by the dolomite supplement should also be slower in the cooler soils. The effect of soil temperature on the ammonification of urea is difficult to predict in view of the evidence that this conversion appears not to be directly biological in nature.

It would appear from general consideration, therefore, that fertilizers should be formulated with regard to the temperatures of soils in which they are to be used, particularly with reference to the acidity-basicity factors.

The ammonia injury factor (4) would, however, be most pronounced with the organic materials inasmuch as the lime supplement would supply calcium and magnesium for the prevention of the injury. There are limits to this protective effect, however, and calcium and magnesium salts cannot fully prevent ammonia injury if the concentration of the latter component of the fertilizer exceeds the limits of tolerance exhibited by the plants (5).

In consideration of the more rapid ammonification of urea it would seem that the tolerance to this material should be less than that of cottonseed meal or similar organic ammoniates when equivalent amounts of nitrogen are involved. From the data it would appear that the nutritive and also the injury values of urea would be about twice those of the natural organic materials.

It is customary to evaluate fertilizer materials relative to their effects when used with superphosphate containing an abundance of calcium salts. In fertilizers containing relatively low concentrations of calcium the tolerance of plants to the organic ammoniates would be greatly lessened and it is doubtful that the calcium or magnesium from limestone supplements alone would appreciably correct the ammonia injury factor.

It is commonly stated that the value of the natural organic material lies in the property of becoming available slowly and furnishing a supply of nitrogen throughout the growing season. This supposed virtue is debatable in view of the evidence that fully one-half of the nitrogen from cottonseed meal is converted to ammonia within 2

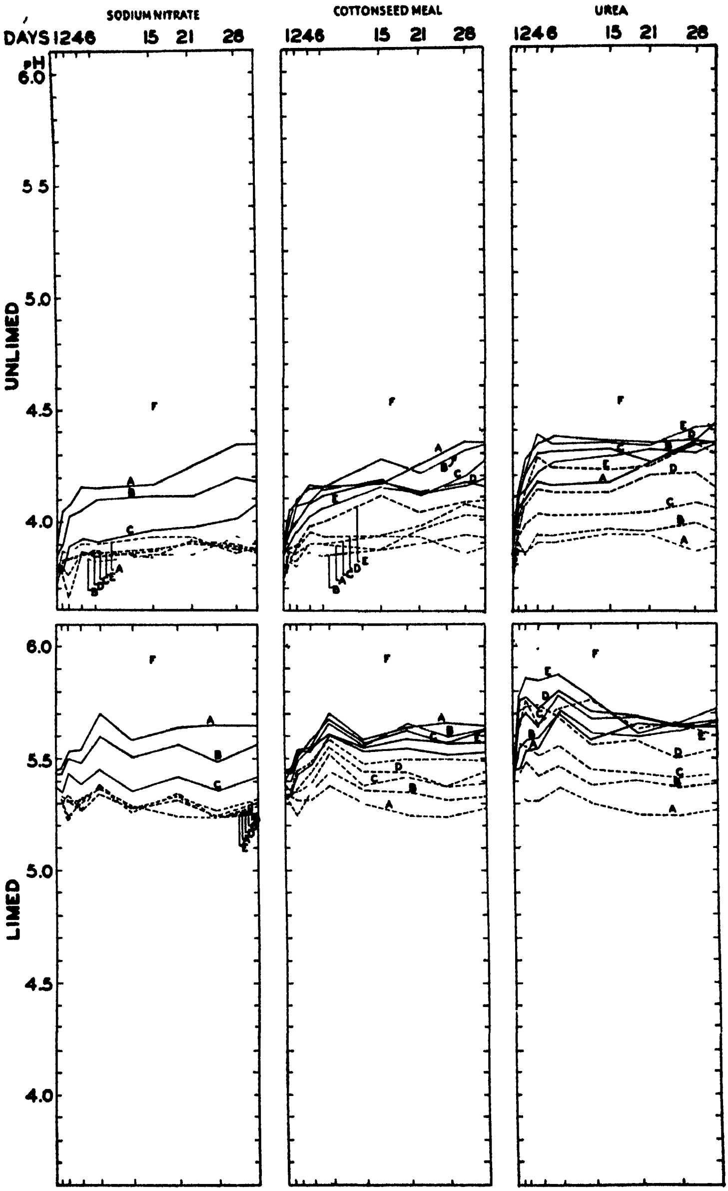

FIG. 7.—Coxville sandy loam.

Broken lines, fertilizers without dolomitic limestone; solid lines, fertilizers supplemented with dolomitic limestone; dotted lines, unfertilized or check. Curves, A, all ammonium sulfate; B, three-fourths ammonium sulfate; C, one-half ammonium sulfate; D, one-fourth ammonium sulfate; E, no ammonium sulfate; F, check.

weeks after addition to the soil. Furthermore, the rate of application of the fertilizer is involved. If, for example, it should be found in experimentation that a fertilizer containing 4% of nitrogen applied at a rate of 600 pounds to the acre is most efficient when one-fourth of the nitrogen is derived from organic sources, it does not follow that this ratio is the optimum for other rates of application. In the former case there would be supplied 6 pounds of nitrogen to the acre from the organic materials. If one-half of this becomes available within 2 weeks, there would remain for use by the crop during the remainder of the season only 3 pounds of nitrogen.

If the virtue of the organic ammoniates should lie in the neutralizing value of the ammonia produced on decomposition, the rate of application would constitute a variable relative to efficiency that could not be controlled in practice.

The similarity between urea and cottonseed meal in regard to ammonia production would indicate, however, that the urea could be substituted wholly or in part for the high grade natural organic ammoniates in all fertilizers supplying nitrogen to the soil in amounts that would furnish negligible quantities of slowly available nitrogen. The difference in cost of the two classes of materials would then constitute a practical consideration inasmuch as those who apply fertilizers at less than the rates used in experimentation would pay little premium for fertilizers containing urea, while those who practice more liberal fertilization would suffer little or no loss due to the difference in the efficiency of the two classes of materials. These assumptions are based on the hypothesis, supported by the evidence in this work, that an important function of the whole group of organic ammoniates is to accomplish the prompt neutralization of the acidity developed immediately upon the addition of fertilizer to the soil.

SUMMARY

A study was made of the early neutralizing effect of the organic ammoniates, cottonseed meal, and urea in comparison to that of dolomitic limestone used at rates calculated to produce a non-acid-forming fertilizer.

Complete fertilizers of various formulas (13 in number) were mixed in potted soils which were kept at a constant temperature and moisture content and the trends of the soil reaction were followed by making pH determinations of the soil at frequent intervals. The analysis of all the fertilizers was 3–8–6. The potash and phosphoric acid in all formulas came from the same sources. The nitrogen was supplied by ammonium sulfate alone and mixed with sodium nitrate, cottonseed meal, or urea. These fertilizers were applied to four soils at two different pH ranges, without dolomitic limestone supplements and with dolomitic limestone supplements in amounts calculated to produce non-acid-forming fertilizers. The soils were used as they came from the field and after treatment with additions of lime (precipitated calcium carbonate) intended to give a pH value of the soil between 6.0 and 7.0.

In all cases on mixing the fertilizers with the soil, a drop in the pH of the soil ranging from 0.6 to over 1.0 unit took place immediately. This drop is due to a salt effect.

The reaction trends of the various fertilizers for the soils used are very similar except for the Coxville soil in which case the magnitude of the reaction change is smaller due to a high content of organic buffering material.

In the unlimed soils for fertilizers without dolomitic supplements, the reaction trends for the fertilizers containing ammonium sulfate and sodium nitrate are virtually identical, there being generally a slight rise in pH following the initial decrease. For fertilizers containing cottonseed meal and urea the rise in pH was significant and was proportional to the amounts of these materials in the fertilizers. The increases in pH were rapid during the first few days followed by a further slow increase for the entire period relative to the unfertilized soil. Maximum pH values of the soil were reached in 1 to 6 days with urea and in 5 to 6 days with cottonseed meal.

With dolomitic limestone supplements (unlimed soil), the ammonium sulfate fertilizers gave a pH rise greater than that of the sodium nitrate or cottonseed meal fertilizers. It was surpassed only by the pH rise for the fertilizers containing the larger increments of urea.

Relative to the pH values of unfertilized soil, none of the fertilizer formulas gave evidence of as great a neutralizing effect in the limed soil as in the corresponding soil unlimed, nor was the range in pH values produced by the organic ammoniates without dolomite as great as in the unlimed soils.

The maximum pH values reached by the fertilizer in which all the nitrogen was in the form of cottonseed meal without dolomite was approximately the same as that found in the corresponding treatment where urea was the source of one-half of the nitrogen. Assuming that the urea was ammonified within a period of a week under the conditions of the experiment, it seems that one-half of the cottonseed meal was ammonified within this period.

For a period after the application of fertilizers the organic ammoniates can serve as neutralizing agents almost as extensively as can a dolomite supplement.

Results in this work indicate that the value of natural organic ammoniates as they are used in mixed fertilizers does not lie solely in the property of becoming available slowly and furnishing a supply of nitrogen throughout the growing season. An important function of the whole group of organic ammoniates, including urea, is to accomplish the prompt neutralization of the acidity developed upon the addition of a fertilizer to the soil.

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THE BIOLOGICAL EFFECT OF AVAILABLE PHOSPHORUS IN HAWAIIAN SOILS[1]

A. FLOYD HECK[2]

PHOSPHORUS is not only a very important plant food, but it is also one of the outstanding factors affecting the rate of biological activity in the soil. Phosphorus has usually been considered an aid to nitrification, but the effect of phosphorus on this process may be reversed by increasing the amount of available carbonaceous energy material in the soil. In this case the phosphorus also stimulates biological action, but with an entirely different set of organisms and with an entirely different effect. This increased biological action results in a more rapid utilization of mineral nitrogen by the soil microorganisms, and a more complete change of this nitrogen into organic form in the micro-organic tissue. From a practical point of view, this action of the phosphorus is distinctly beneficial in at least three ways, *viz.*, (a) the leaching of inorganic nitrogen by irrigation water is greatly reduced because of the reduction of inorganic nitrogen, (b) the availability of the nitrogen is better distributed throughout the growing season, and (c) the amount of phosphorus in the organic or biological balance is greatly increased.

EXPERIMENTAL

In June 1930, a set of plats was laid out at the Waipio Substation of the Experiment Station, Hawaiian Sugar Planters' Association, in which sodium nitrate was used in combination with molasses and with molasses and rock phosphate in the fertilization of cane. During the latter part of June, 1930, the fertilizers were applied in the line (row), the cane planted, and irrigation water applied in the normal manner. The three plats used in this connection were fertilized before planting as follows:

Plat 2. Sodium nitrate, 1,500 pounds an acre.
Plat 4. Sodium nitrate, 1,500 pounds an acre.
Waste molasses, 10 tons an acre.
Plat 15. Sodium nitrate, 1,500 pounds an acre.
Waste molasses, 10 ton an acre.
Rock phosphate, 6 tons an acre.

On September 29, and again on November 5, 1930, these plats were sampled by 12-inch depths to a total depth of 6 feet and the nitrate nitrogen determined. The results are given in Tables 1 and 2.

Nitrate nitrogen is soluble in water and remains so in the soil solution. Under irrigation the nitrate moves with the irrigation water. The downward movement, however, is usually greater than the return, with the net result that under irrigation nitrate nitrogen tends

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TABLE 1.—*Nitrate nitrogen in the soil under growing cane at the Waipio Substation, September 29 and November 5, 1930, cane planted and fertilized the latter part of June, 1930.*

Plat No.	Nitrate nitrogen, p.p.m.							
	1st 6 in.	2d 6 in.	2d foot	3d foot	4th foot	5th foot	6th foot	Total 6 feet
				Sept. 29, 1930				
2	1.4	5.5	38.0	85.0	38.0	10.0	6.0	184.0
4	1.5	4.5	31.0	68.0	25.0	10.0	4.0	134.0
15	1.7	4.5	12.5	37.0	23.0	9.0	3.0	90.7
				Nov. 5, 1930				
2	1.2	13.0	30.0	85.0	32.0	10.0	6.0	177.2
4	2.5	3.1	3.1	32.0	59.0	11.7	3.5	123.9
15	4.4	3.0	13.0	23.0	9.2	3.4	2.1	58.1

TABLE 2.—*The effect of molasses and phosphorus on the change of inorganic nitrogen to the organic form.*

Treatment in addition to nitrogen	Inorganic nitrogen changed to the organic form	
	p.p.m.	Percentage of applied nitrogen*
	Sept. 29, 1930	
Molasses and phosphorus	93.3	50.6
Molasses	50.0	27.2
Change due to phosphorus	43.3	23.4
	Nov. 5, 1930	
Molasses and phosphorus	109.1	61.7
Molasses	43.3	24.5
Change due to phosphorus	65.8	37.2

*Based on the nitrate nitrogen found in plat 2 (nitrate alone) for each date.

to be leached into the subsoil. Fig. 1 shows that the applied nitrate in this work had moved downward over 3 feet in a period of 3 months. The extent of this movement will depend much upon the amount and frequency of irrigation, and especially upon the amount of excess irrigation water used. When sodium nitrate was used alone, practically all of the applied nitrogen was found in the soil as nitrate, but at a point 3 feet below the surface where it was applied. Where molasses was applied along with the nitrate, the sugar in the molasses caused a rapid growth of micro-organisms (1)[8] which caused part of the nitrate nitrogen to be changed to the organic form in the micro-organic tissue. The nitrogen so changed is held in the surface soil for later use by the cane. In this work the data indicate that about one-fourth of the nitrogen was held in this way as the result of the molasses alone.

[8]Figures in parenthesis refer to "Literature Cited," p. 851.

If, in addition to the molasses, available phosphorus is also supplied, the biological action is more rapid and seems to extend over a much longer period of time, and in this experiment, resulted in the combination of as much as 60% of the applied nitrate nitrogen into micro-organic form. Thus, the use of phosphorus with the energy material of the molasses more than doubled the effectiveness of the

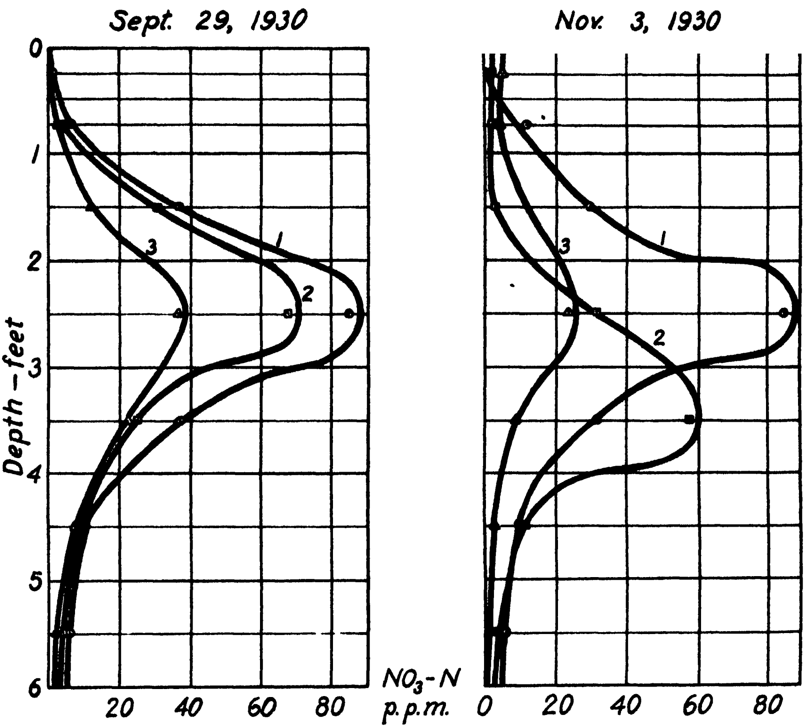

FIG. 1.—Distribution of nitrate nitrogen under lines of cane at the Waipio Substation after an application of sodium nitrate to the surface soil at planting time, June 1930, at the rate of 250 pounds of nitrate nitrogen an acre. The graphs show the effect of molasses and phosphorus on the quantity and distribution of the remaining nitrate. 1, sodium nitrate alone; 2, sodium nitrate and molasses; 3, sodium nitrate, molasses, and rock phosphate.

molasses in the prevention of leaching. Phosphorus alone, however, showed very little, if any, tendency to bring about this effect. It seems from the data that the sugar in the molasses is essential in building up and maintaining a biological balance (2) and combining into organic form a large amount of nitrogen and phosphorus into the micro-organic tissue which is produced. No doubt, this is due to the rapid growth of yeasts during the decomposition of the sugars in the molasses. If the molasses is burned or treated in any way in which its sugar is destroyed, most of its biological effect is lost and its value is reduced to the mere value of the mineral salts which it contains (3).

On November 5, the plat receiving the rock phosphate along with sodium nitrate and molasses had a higher nitrate content in the surface 6 inches than any other plat. This indicates that most of the available energy material in the molasses had been used up, and at that time, the phosphorus was aiding in the nitrification process, so that the nitrogen which had been changed to the organic form and held in the surface soil was then being slowly changed again to nitrate for use of the cane. In this way the nitrogen is held in the surface soil against leaching and also the supply of nitrate nitrogen is made more constant over a longer period of time. It is more than possible that a certain amount of phosphorus is also made available from the organic material in much the same way as is the nitrogen.

No yield data were obtained of this cane, nor were the phosphorus or potassium contents of the juice determined.[4] At the age of 7 months the plat treated with phosphorus in addition to molasses and nitrate was easily 25% better in growth of cane than either nitrate alone, nitrate and molasses, or nitrate and phosphorus. The sugar content of the cane juice was much the same for all plats at this stage of growth.

DISCUSSION

The presence of carbonaceous energy materials in the soil facilitates the growth of yeasts and fungi, and these use up nitrogen in their growth and change the soluble inorganic nitrogen in the soil to organic nitrogen in micro-organic form in the cell structure of these organisms. Available phosphorus accelerates this process and in the work reported in this paper has more than doubled the amount of mineral nitrogen changed to the organic form. In this process, phosphorus is also built up into the micro-organic tissue. There is little doubt that this phosphorus is largely organic in nature and its availability and utilization by crops must depend upon biological activity to a large extent. So long as there is available energy material present in the soil, nitrogen and phosphorus will both be changed to the organic form. As soon as this energy material is used up these organisms stop growing and an entirely different set of organisms become active. With these latter organisms, the reaction is reversed and nitrogen and phosphorus are again liberated in the inorganic form for use of the growing plant.

The nitrogen is liberated as nitrate, which is soluble in the soil solution and is either used by the plant or leached into the subsoil. The story of phorphorus, however, is entirely different. When the organic phosphorus is liberated as phosphoric acid in the soil solution it immediately becomes a part of an inorganic phosphate equilibrium which the author (4) has proposed as an explanation for the slow fixation of quickly to slowly available phosphates. In this way there is a definite relation between the phosphorus in the organic or micro-organic form and that in the inorganic form. In this relation it does not seem out of place to think of soil phosphorus as being distributed throughout a rather complex equilibrium made up of an organic or biological phase, on the one hand, and the inorganic

[4]Work was discontinued February 10, 1931.

equilibrium or mineral phase on the other, with both phases in equilibrium biologically with each other. The direction and rate of any shift of phosphorus in this complex equilibrium will depend very much upon the rate and kind of biological activity, and this in turn on the amount and kind of carbonaceous material in the soil.

In this connection a very interesting relationship may be seen between the biological activity and the availability of the phosphorus in the soil. Since phosphorus aids biological activity which in turn tends to push the phosphorus equilibrium in the direction of the organic end, the action becomes mutually helpful to both the biological activity and also to the increase of more quickly available phosphorus. This is especially true in soils where most of the phosphorus is in the more slowly available forms, as is often true in Hawaiian soils, especially in the red or yellow soils. In these soils biological activity and the maintenance of an active biological balance becomes doubly important. Because of the nature of the cropping system in the cane lands of Hawaii, it is hard to introduce organic matter to maintain this balance and as a result it has been largely neglected. However, the use of waste molasses for this purpose is quite possible and has been employed on some plantations in a very practical way and with little expense. This seems to be a rather simple way to dispose of the waste molasses and at the same time the sugar planter is able to maintain the biological activity in his soil at a higher level. The molasses also furnishes considerable available potash.

SUMMARY

In the presence of available energy material, the biological activity in Hawaiian laterites is greatly stimulated by the presence of available phosphorus, when measured by the assimilation of nitrate nitrogen by micro-organisms. In this combination with energy material, phosphorus helps prevent leaching of mineral nitrogen and also helps to build up a larger biological balance in the soil, which in turn increases the amount of phosphorus as well as nitrogen held in the organic form, thus increasing the availability of the phosphorus.

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AGRONOMIC AFFAIRS

PRELIMINARY ANNOUNCEMENT OF THE PROGRAM OF THE SOILS SECTION OF THE SOCIETY

PROGRAM OF GENERAL SECTION

THURSDAY, DECEMBER 5

Morning: General Session of the Society.
Afternoon: Joint program with the American Soil Survey Association, 1:30 to 4:30, with brief summaries of the most important papers given before the various Commissions of the International Congress of Soil Science.

PROGRAM OF SOIL CHEMISTRY AND SOIL FERTILITY SUB-SECTION, DR. R. H. BRAY

CHEMISTRY

Thursday, 4:30– 6:00: Soil Testing.
Friday, 9:00–12:00: The Availability of Soil Potassium.

FERTILITY

Friday, 9:00–12:00: Soil Problems in Dry Land Farming, Dr. John S. Cole.
Friday, 1:30– 4:00: Papers Dealing with General Problems of Soil Fertility.

PROGRAM OF SOIL PHYSICS SUB-SECTION, DR. L. B. OLMSTEAD

Friday, 9:00–12:00: Physical Soil Constants.
Friday, 1:30– 4:00: Joint Session with Soil Chemistry; Physical and Chemical Studies of Soil Colloids.

PROGRAM OF SOIL BACTERIOLOGY, DR. H. W. BATCHELOR

Friday: as announced in September number of JOURNAL.

Wednesday afternoon there will be a program dealing with land utilization, under the direction of Dr. Morgan and Dr. Hutton, representing committees of the Soil Survey Association, and Dr. Bray, representing the Soils Section of the American Society of Agronomy.

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THE PLACE OF NITROGEN FERTILIZERS IN A PASTURE FERTILIZATION PROGRAM[1]

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A review of the literature on the use of nitrogen fertilizers on pasture land would be so extensive that this discussion is being confined to Ohio conditions and Ohio experiments. The splendid and well-known works of Vinall (1)[3], Fink, *et al.* (2), Brown (3), and many others are therefore omitted from discussion. Also, for the sake of brevity, detailed descriptions of the Ohio experiments referred to are being omitted.

In recent years it has become rather generally recognized that the margin of profit in most phases of livestock production is dependent upon the extent to which good pasture is utilized in its production. There are probably no other means of so greatly reducing the cost of production of livestock and livestock products as through improvement in the production and grazing of farm pastures. We are here considering the place of nitrogen fertilizers in such a pasture improvement program. In this respect we are concerned with the following questions:

1. When do nitrogen fertilizers give increased growth?
2. How much increased growth do they give?
3. What is the analysis of this increase?
4. Does it pay for the cost of production?
5. What is the place of nitrogen fertilizer in a well-balanced program?

EXPERIMENT 1

In 1928 there was begun at Columbus (4) a study of the effect of nitrogen fertilizers on Kentucky bluegrass sod. This involved, among other things, different rates of application. The area was of rather high productivity at the beginning of the experiment, consequently increases were not so great as in some other experiments, being only 2,195 pounds of dry matter and 631 pounds of protein where 200

[1]Contribution from the Department of Agronomy, Ohio State University, Columbus, Ohio, and the Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication July 11, 1935.

[2]Extension Agronomist, Ohio State University; and Associate Agronomist, Ohio Agricultural Experiment Station.

[3]Reference by number is to "Literature Cited", p. 862.

pounds of the element nitrogen had been applied. At all times throughout the season and at all rates of application the production was greater on the nitrogen areas than on the check areas.

Outstanding features of this experiment, however, were the continued response in both dry matter and percentage of protein for successive additions of nitrogen up to the 200 pounds. In 1929, for example, the increase in pounds of protein resulting from the second 100 pounds of nitrogen was greater than from the first 100 pounds. The additional dry matter and protein might be expressed as 2,195 pounds of a 28.7 dairy feed. The dairy feed would cost much more than a nitrogen fertilizer carrying 200 pounds of nitrogen.

Under conditions of this experiment, if buying barn feed had been the alternative to the use of nitrogen even up to the rate of 1,000 pounds of a 20% carrier per acre, the latter would have been the more economical procedure. The actual average yields of the check plats were 1,932 pounds of dry matter and 310 pounds of protein in 1928 and 3,093 pounds of dry matter and 618 pounds of protein in 1929. The increases over these checks obtained from different rates of application of nitrogen are given in Table 1.

TABLE 1.—*Increased production resulting from various amounts of nitrogen per acre used as top dressing on bluegrass sod, Columbus, Ohio.**

Pounds of nitrogen	Dry matter, lbs. per acre	Protein, lbs. per acre	Protein of dry matter %	Nitrogen recovery %
		1928 results		
50	602	104	17.3	33.3
100	1,178	234	19.8	37.4
200	2,173	482	22.2	38.6
		1929 results		
50	958	184	19.2	58.9
100	1,328	314	23.6	50.2
200	2,195	631	28.7	50.4

*Nitrogen applied in two applications, March 15 and June 15.

EXPERIMENT 2

In 1929, another experiment in which nitrogen fertilizer was applied to a Kentucky bluegrass sod at 40-day intervals was started near Dayton (5). The main areas were grazed, but check areas were reserved for mechanical harvests. After 2 years at the original location it became necessary in 1931 to transfer the experiment to another location near Springfield.

The sod at the beginning of the experiment in both locations was what farmers would describe as very good. The period covered by this experiment was not favorable for large returns from nitrogen and the yields, as indicated by the special harvests, were low; but again, as in experiment 1, production of the treated areas remained above the checks throughout the season and represented a more economical source of feed than the commercial market.

In this experiment, however, the pasture was utilized by beef animals and records were kept of the gains produced. A summarization of these results for the 3 years of the experiment is given in Table 2.

TABLE 2.—*Production per acre of dry matter, protein, and beef; relationship of gains in beef to dry matter consumed; and fertilizer cost of production resulting from topdressings of nitrogen on bluegrass pasture near Dayton and Springfield, Ohio.**

	1929		1930		1931	
	With nitrogen	Without nitrogen	With nitrogen	Without nitrogen	With nitrogen	Without nitrogen
Dry matter, lbs.	2,948	2,048	2,131	1,315	5,501	4,827
Protein, lbs.	458	275	396	192	878	756
Beef, lbs.	177	98	260	103	297	200
Grass, in terms of dry matter, consumed per lb. of beef produced	16.6	20.9	8.2	12.7	18.6	24.1
Fertilizer cost per 100 lbs. of beef with N at 10c per lb.	$8.48		$2.87		$4.64	

*Nitrogen used: 67.5 lbs. in 1929; 45 lbs. in 1930 and 1931. Applied in lots of 15 lbs. each at 40-day intervals, beginning April 14, 1929, April 1, 1930, and April 9, 1931. Last treatment in 1929 at half rate.
Cattle: Angus steers in 1929, cows and heifers in 1930, mixed steers in 1931.

EXPERIMENT 3

A third experiment was begun in 1929 and continued to 1933 in which similar tests were made at the substations in Belmont, Trumbull, and Hamilton counties. Here, as at Dayton and Springfield, nitrogen was applied at 40-day intervals, the quantity per application being 15 pounds. No grazing data were obtained but check areas were harvested 40 days after treatment throughout the season. The locations and seasons were more favorable to nitrogen response and yields were much greater than in experiments 1 and 2. The summarization for the three stations for the 4 years is contained in Table 3. Of particular interest was the consistent and definite manner in which the plats receiving nitrogen April 1 and the corresponding checks fell below those receiving their first nitrogen treatment later and their corresponding checks. The difference was probably due to the earlier cutting of the first plats. The harvests were made by a sickle and were rather close. This illustrates how a possible gain from nitrogen fertilizer may be offset by improper or untimely grazing.

EXPERIMENT 4

The next experiment with which we are concerned was started in 1931 on 43 farms in southeastern Ohio (6). In these tests, nitrogen was applied at two rates, 25 and 50 pounds, and in each case all in a single application between March 25 and April 25. Data were kept on changes in vegetative cover and fertilizer response. In Table 4 is

TABLE 3.—*Average yield and increase per acre of dry matter and protein and percentage of nitrogen recovered from 60 pounds of nitrogen applied to bluegrass pasture in four 15-pound applications at 40-day intervals, beginning about April 1 for plat 1, April 10 for plat 2, April 20 for plat 3, and April 30 for plat 4, Belmont, Trumbull, and Hamilton farms, 1929–33.**

Approximate date of first application	Yield, pounds		Increase, pounds		Nitrogen recovered %
	Dry matter	Protein	Dry matter	Protein	
April 1, check	1,974	275	—	—	—
April 1	3,349	536	1,375	261	69.7
April 10, check	1,828	259	—	—	—
April 10	4,226	707	2,398	448	102.7
April 20, check	2,261	301	—	—	—
April 20	4,767	809	2,506	508	135.3
April 30, check	2,720	345	—	—	—
April 30	5,247	874	2,527	529	141.0

*All plats received a basic treatment of superphosphate or 0-14-6.

given the summary of changes in vegetative cover, the complete fertilizer plat being the one receiving 50 pounds of nitrogen.

TABLE 4.—*Average composition of soil cover and percentage of bare ground in 1933 on plats in 44 pasture tests begun in 1931 in southeastern Ohio.*

Fertilizer treatment	Percentage of various types of vegetation and bare ground in soil cover				
	All clovers	Tame grass	Wild grass	Weeds	Bare ground
None	11	30	9	20	30
Phosphate	22	43	5	15	15
Phosphate and potash	25	43	5	13	14
Complete fertilizer	20	62	3	10	5

In Table 5 are presented the increases in dry matter for the years 1931, 1932, 1933, and 1934 for 25 and 50 pounds of nitrogen, respectively, over the phosphate-potash plat.

The nitrogen in this experiment, as in the others, produced feed at a much lower cost than the current commercial price for equivalent feeds. The second increment of nitrogen was also as effective as the first.

By means of factors determined from consideration of feeding standards, grazing experiments, and herbage composition and analysis, an attempt was made to express the gains made from various treatments in terms of beef and milk production. The results of these calculations indicated that phosphate fertilizer had greatly reduced the pasture cost per 100 pounds of possible milk and beef production

and that nitrogen, in addition to phosphorus, had greatly increased the possible production of milk and beef but had not further lowered the cost per unit. The livestock very generally showed a preference for the grass of the nitrogen-treated areas. This was true also in other grazing experiments referred to.

TABLE 5.—*Response in increased yield of dry matter per acre resulting from nitrogen topdressing of bluegrass pasture.*

Pounds nitrogen applied	Increase of dry matter over phosphate-potash plat				
	1931 (43 tests)	1932 (36 tests)	1933 (34 tests)	1934 (30 tests)	Average
25	955	576	1,085	838	863
50	2,057	1,335	2,037	1,060	1,622

Where areas were permitted to make excessive growth and were then cut off close with a sickle in early June in hot dry weather, much damage to the stand and yield during the balance of the season resulted.

A further study of the data in this experiment indicated rather conclusively that nitrogen was relatively much more effective in non-white clover years and on pastures where white clover had not been prevalent. Moisture and height of grazing were apparently the chief factors in determining the white clover content of pastures which had sufficient lime and phosphate.

EXPERIMENT 5

Experiment 5 was started at Columbus in the spring of 1934. Nitrogen was applied to a good Kentucky bluegrass sod at the rates and in the amounts indicated in Table 6 and gave responses by months as shown in the same table. Due to a very unfavorable growing season, all yields were low and the results are for a single year. They are given in detail since they represent the same tendencies pointed out in a general way in previous experiments.

EXPERIMENT 6

A sixth experiment was started at the Schaaf Dairy Farm near Columbus in 1929 (7, 8). This was a rotational grazing experiment involving 60 to 70 cows and 30 acres of good Kentucky bluegrass divided into six paddocks. In addition to a basic treatment of 500 pounds of 20% superphosphate and 120 pounds of muriate of potash per acre, applied in the spring of 1929, four applications of sulfate of ammonia, totaling 500 pounds were made in 1929 and 1931. In 1930, a drouth year, only three applications totaling 400 pounds were made.

In addition to the complete fertilizer grazing areas, the experiment also included small areas with different fertilizer treatments for the purpose of determining by artificial harvests the relative production

TABLE 6.—*Yield of dry matter and protein in pounds per acre resulting from nitrogen topdressing bluegrass pasture, 1934.*

Treatment	April		May		June		July		August		September		Total	
	Dry matter	Protein	Dry matter	Protein	Dry matter	Protein	Dry matter	Protein	Dry matter	Protein	Dry matter	Protein	Dry matter	Protein
No nitrogen	276	50	388	56	84	13	69	17	393	71	64	10	1,274	217
20.5 lbs. N, Apr. 5	361	81	608	94	99	15	83	16	453	85	70	12	1,674	303
41.0 lbs. N, Apr. 5	360	93	748	136	119	19	93	18	486	82	92	15	1,898	363
61.5 lbs. N, Apr. 5	433	116	867	162	121	20	98	20	524	107	107	19	2,150	444
20.5 lbs. N, Apr. 5, June 1, and Sept. 1	304	69	592	94	158	25	136	30	540	105	204	44	1,934	367

TABLE 7.—*Average yields and increases per acre of dry matter and protein and percentage of protein, Schaaf dairy pasture.*

Treatment	1929			1930			1931		
	Pounds dry matter	Pounds protein	Protein %	Pounds dry matter	Pounds protein	Protein %	Pounds dry matter	Pounds protein	Protein %
None	2,241	358.7	16.0	541	102.5	18.9	2,037	380.6	18.7
PK	2,749	476.5	17.3	785	165.0	21.0	2,631	471.7	17.9
NPK	4,328	845.9	19.5	1,479	352.0	23.8	4,355	936.7	21.5
				Increases					
PK over Ck	508	117.8	23.1	244	62.5	25.6	594	91.1	15.4
NPK over Ck	2,087	487.2	23.3	938	249.5	26.6	2,318	556.1	24.0
NPK over PK	1,579	369.4	23.4	694	187.0	26.9	1,724	465.0	27.0

of phosphate and potash in combination but without the nitrogen. The results obtained from these small areas are summarized in Table 7.

The production for the NPK plats was always above the PK and check plats throughout the season. The margin by which the complete fertilizer plats excelled, however, was greater in the spring and fall than in mid-summer. The PK plats showed the same tendency to run ahead of the check plats in production in midsummer and fall as well as in the early part of the season. This was true in 11 out of 12 comparisons in July and again in August. The season was so abnormally dry in 1930 that yields for that year, as indicated in Table 7, are not in line with the other two years and might be ignored.

Assuming that the mineral fertilizers would last over a period of 4 years, \$2.31 worth of superphosphate and potash produced 508 pounds of a 23.1% protein feed in 1929 and 594 pounds of a 15.4% protein feed in 1931. In comparison to this \$7.50 worth of nitrogen fertilizer produced 1,579 pounds of a 23.4% protein feed in 1929 and 1,724 pounds of a 27.0% protein feed in 1931. This again is a much smaller amount of money than would be required to purchase a more or less comparable feed on the general market. There is, of course, the possibility that such feed might be produced by some other means on the farm for less than the general market price.

Results from grazing.—The nitrogen fertilizer more than doubled the carrying capacity of the pasture. While the estimated carrying capacity at the beginning of the test was 0.73 cow per acre for 155 days, it was actually 1.82 cows per acre for 173 days in 1929, 0.90 cow per acre for 184 days in 1930, and 1.82 cows per acre for 172 days in 1931. Records were kept of feed consumed and milk produced, but since the cows were at all times on manger feed, it would hardly be fair to attribute all gain above feed cost to pasture. It happened, however, that June and July of 1930 produced no pasture. From feeding costs during these 2 months and from costs at the beginning and end of the pasture season, it was possible to determine the feed cost per cow without pasture. This has been taken advantage of in calculating the value, in terms of manger feed replaced, of the pasture produced by the complete fetilizer treatment. This total value has been apportioned to the credit of nitrogen, phosphate and potash, and normal response without treatment in proportion to the yields of dry matter resulting from these three factors as reported in Table 7. The results of this apportionment are given in Table 8.

It is obvious from the data of Table 6 that the increased production resulting from fertilization was of higher analysis and doubtless of greater feed value than that of the natural production without fertilizer. This being the case, the actual value of the grazed herbage resulting from fertilization should doubtless be slightly greater and that resulting from natural productivity slightly less than indicated in Table 8.

The prices assigned to the various feeds replaced are probably as low as those for which most farmers would be willing to produce these products. Since the fertilizers still show a satisfactory return, it would appear that at least on dairy farms where high-quality pasture

can be utilized, the use of nitrogen fertilizer on pasture is thoroughly justified.

TABLE 8.—*Acre value of pasture herbage produced, cost of fertilizers (applied), and net difference, calculated on basis of manger feed replaced.**

Items	Dollars per acre		
	1929	1930	1931
Value of herbage on complete treatment area	$56.35	$20.87	$53.09
Value of herbage due to natural production	29.87	6.51	24.42
Value of herbage due to nitrogen fertilizer	20.05	10.62	21.33
Value of herbage due to phosphate and potash	6.43	3.74	7.34
Cost of nitrogen (applied)	8.50	6.75	8.50
Cost of phosphate and potash (applied)	3.17	3.17	3.17
Return from nitrogen above cost	11.55	3.87	12.83
Return from phosphate and potash above cost	3.26	0.57	4.17

*Feed prices assumed for these calculations: Western alfalfa hay $15.00 per ton; local alfalfa hay $12.00 per ton; clover, soybean and mixed hay $10.00 per ton; timothy hay $8.00 per ton; silage $4.00 per ton; grain ration $25.00 per ton.

SUMMARY OF EXPERIMENTS

Six Ohio experiments involving the use of nitrogen fertilizers on Kentucky bluegrass pasture have been briefly presented. The data indicate that:

1. Nitrogen-fertilized grass is more palatable and is grazed more closely than adjoining areas of grass which have had no nitrogen.
2. Early clipping, intended to approximate early close grazing, greatly reduced the effectiveness of nitrogen in increasing grass yield.
3. Close clipping in June in hot dry seasons, intended to approximate close grazing of areas earlier, permitted excessive growth, greatly reduced the stand and the yield later in the season and consequently the possible return from fertilization.
4. Nitrogen fertilizer applied early in the spring increased the production not only in the early spring but throughout the season, as indicated by regular and uniform mechanical harvests. With different soil conditions or with limited mineral nutrients this might have been different. The increased production during July and August, however, was so little that this could not be considered as a means of meeting the mid-summer pasture shortage.
5. Making a second or third application of nitrogen later in the season materially increased the fall growth.
6. The exact time of response in extra growth resulting from nitrogen treatments appeared to be dependent upon moisture and temperature conditions. Good growth was obtained in both July and August under favorable moisture conditions.
7. Nitrogen was relatively less effective on sods carrying a high white clover content and in years of high white clover content. The percentage of white clover appeared to fluctuate from year to year depending largely upon moisture and temperature conditions.
8. Nitrogen applied to sods already well supplied with lime and phosphate produced feed at a much lower cost than feeds of similar analysis could be purchased on the market.

9. The law of diminishing returns from increased applications of nitrogen fertilizer appeared to operate at a much higher level than had been previously generally assumed. It appears that the rate of application of such fertilizer up to at least 60 pounds of nitrogen per acre should, in general practice, be determined largely by the amount of pasture required.

THE OHIO PASTURE PROGRAM WHERE PERMANENT PASTURE IS AVAILABLE

In Ohio good response has been obtained from lime, phosphate, and manure on the generally depleted pasture areas. These materials cost less than nitrogen, they need not be applied so frequently, and the first two appear to be essential to satisfactory returns from nitrogen. The Ohio pasture improvement program, therefore, begins with the use of these materials. Once they have been applied to the general pasture area, there may yet be a shortage of pasture in early spring and July and August or in some instances even in the main grazing season.

For this early spring period it is recommended that an area of good bluegrass sod be set aside. In addition to periodic applications of lime, if needed, phosphate, and possibly manure, this area should receive annually early in the spring a liberal application of nitrogen fertilizer. Since livestock will show a preference for this nitrogen area and are likely to over-graze it later, it must be fenced separately from the main pasture area and protected from over-grazing. Little or no grazing should be permitted after September 1. In event a Kentucky bluegrass sod is not available, timothy, orchard grass, or tall meadow oat grass may be used, or a special crop such as rye may be substituted.

For the July-August period Sudan grass, alfalfa, or alfalfa mixtures are recommended.

Should this leave a shortage in the main grazing season, nitrogen may be applied to the main pasture area further to boost growth at that time. This would be especially desirable in years of a low white clover content, which may be determined by observation of weather condition and clover content the previous fall.

This program is presented in graphic form in Fig. 1.

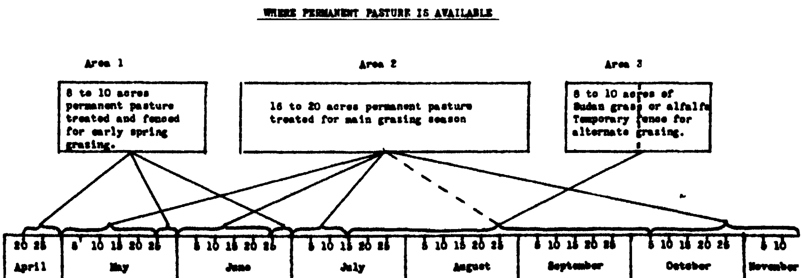

FIG. 1.—Suggested plan for pasture for 24 cows for the entire grazing season.

There is probably no other means of so greatly reducing the cost of livestock and milk production and increasing the net farm income on the average Ohio farm as by giving more attention to the pasture program. It is therefore given a major consideration by the college and experiment station. It is recognized, however, that satisfactory returns will result only when fertilization is accompanied by proper management and the extra production is utilized by a good quality of livestock.

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THE DETERMINATION OF THE FORMS OF INORGANIC PHOSPHORUS IN SOILS[1]

R. ANDERSON FISHER AND R. P. THOMAS[2]

SOIL phosphates occur in such a fine state of division and in such small proportions in the soil mass that no satisfactory methods have existed for the estimation of the different forms present. Such a method, however, would be very desirable and probably will form a basis of the eventual laboratory tests of phosphate availability. In the investigation here reported, a rapid method has been developed for estimating the inorganic soil phosphorus contained in four groups of materials based upon relative rates of solution in buffered acid extractants. The four groups are as follows: (A) Amorphous and finely divided crystalline phosphates of calcium, magnesium, and manganese; (B) amorphous phosphates of aluminum and iron; (C) phosphates adsorbed upon hydrous oxides and those present in the form of apatite; and (D) by difference, phosphates present in crystalline phosphates of aluminum and iron.

By placing the proper values upon the phosphorus contained in each group it was found that analyses by this method placed 22 Maryland soils, representing 3 provinces, 7 series, and 12 types, in practically the identical order of phosphorus requirements as that disclosed by pot tests.

METHODS OF PROCEDURE

Preliminary studies upon rates of solution indicated that extractions at two pH values would be necessary in order to distinguish phosphorus present in amorphous and finely divided crystalline phosphates from adsorbed phosphorus and phosphorus present in apatite. Two extractants with pH values of 2 and 5 were adopted for this purpose. The pH 2 solution consists of a 0.002 N sulfuric acid and 0.3% of potassium acid sulfate. The hydrogen-ion concentration of this solution ranged between pH 1.95 and 1.97. This solution was first used in 1932 (Maryland Experiment Station unpublished data) and since has been used by other workers (1)[3]. Experiments have shown that this extraction solution, when used in the usual proportion, changed only 0.35 pH with a soil containing 10% calcium oxide. The second extractant was a buffered solution of acetic acid containing 3.6 ml of concentrated acetic acid per liter and 19.04 grams of sodium acetate. The hydrogen-ion concentration of different lots of solutions made up in this manner had a range in pH value of 4.98 to 5.02. When used to extract soil containing 20% of calcium oxide, the reaction of this extractant changed only 0.30 pH. These two extracting solutions are designated by their respective approximate pH values.

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[3]Figures in parenthesis refer to "Literature Cited", p. 873.

Solubility studies.—As pure phosphorus compounds are not easily separated from soils for study purposes, pure amorphous compounds (freshly prepared and not dehydrated) and crystalline phosphate minerals were used to obtain data upon their rates of solution at the two pH values. Since solubility invariably depends upon the amount of surface exposed, an effort was made to control the surface exposed by passing all materials studied through a 100-mesh sieve and rejecting that part passing a 200-mesh sieve. Amounts of materials were used which gave similar phosphorus concentration in the extraction mixture as was obtained in the extraction of soils low in phosphorus.

Extraction method procedure.—On the basis of the solubility data obtained, the following procedure was formulated for extracting soils to determine the forms of phosphorus:

Weigh out three 2-gram samples of each soil and place in separate 750-ml Erlenmeyer flasks. The soil should be air dry and screened through a 20-mesh screen. Add to two of each set of three flasks, 400 ml each of the pH 5 extractant. An equal volume of the pH 2 solution is added to the third flask of each soil. In order that each soil sample may be placed in contact with extracting solution at the same time, it is desirable to have the solutions measured out ready to add to the respective flasks. After noting the time, stopper and place in an end-over-end shaker. While the flasks are shaking prepare for filtering through either 12.5 cm No. 40 or 11 cm No. 41 Whatman filter paper, or filter papers of equal quality. One-half hour after the extractants were added remove one of the pH 5 extraction flasks for each soil and filter, catching the filtrate in a 250- to 300-ml Erlenmeyer flask. The first 25 to 30 ml should be discarded. Remove funnels from the receiving flasks three quarters of an hour after extractants were added, or 15 minutes after removing from shaker. Only the filtrate which has run through the filter in this time is used for the subsequent phosphorus analysis. Suitable aliquots of the filtrates are taken[4] for the regular colorimetric phosphorus determinations (2). Remove the remainder of the pH 5 flasks at the expiration of 2 hours and filter, removing funnels at 2¼ hours. Determine the phosphorus in these filtrates as before. Terminate the shaking of the pH 2 extractions at 2¾ quarters hours and filter, removing funnels at 3 hours. Phosphorus is determined on the filtered extract in the same manner.

The results obtained by this procedure on 22 Maryland soils and various phosphate minerals and compounds are reported in Tables 1, 2, and 3.

Leaching studies.—Soils and pure phosphate materials were leached with the pH 5 and 2 solutions to ascertain the fractions of "B" and "C" group phosphorus removed by the previously described extraction method. An improved apparatus set up after Russel (4) was employed. The dropping tubes were made of capillary tubing to allow of greater precision in the control of the rate of flow. They were adjusted to drop 200 ml of extractant every 4 hours. Readings were made upon each 200 ml separately. The phosphorus obtained in this manner is reported in Tables 4, 5, 6, and 7.

Crop indexes on soils studied.—Tomatoes and millet were grown in the greenhouse upon the 22 Maryland soils which had been placed in half-gallon glazed pots. Since none of these soils had been recently cultivated or had received fertilizer treatment during the past 10 years, they should not contain any phosphate fertilizer residues. Nitrogen and potassium were added in order to eliminate them as possible growth-limiting factors. Part of each soil received phosphorus.

[4]The ammonium molybdate sulfuric acid reagent for use at pH 5 should contain 370 cc of concentrated sulfuric acid per liter instead of the usual 280 cc.

The responses to a 1,000 pounds per acre application of superphosphate are expressed as percentage increase for the tomato crop in Table 8. The soils are arranged in descending order of crop yield in this table. This arrangement also places them in the order of their increase in soluble or nutritional phosphorus content. A similar response was obtained for the millet. Figs. 1 and 2 show the growth of millet obtained with and without phosphorus treatment for soils 1, 3, and 13.

TABLE 1.—*The phosphorus obtained by the proposed extraction method from 22 Maryland soils.*

No.	Soil type studied	H ion concentration pH	Phosphorus extracted		
			By pH5 solution		By pH 2 solution in 3 hr., p.p.m.
			In ¾ hr., p.p.m.	In 2¼ hr., p.p.m.	
1	Portsmouth loam	4.2	8.00	8.00	125.0
2	Sassafras loamy sand	4.5	1.00	1.00	6.0
3	Elkton loam	5.2	4.75	6.25	27.5
4	Sassafras loam	6.1	3.25	5.25	22.0
5	Sassafras silt loam	5.7	2.25	3.00	23.0
6	Sassafras silt loam	6.2	2.00	4.00	28.5
7	Sassafras silt loam	5.3	2.25	2.87	23.0
8	Keyport silt loam	4.7	5.50	9.00	25.0
9	Elkton silt loam	4.5	2.50	3.12	14.5
10	Keyport loam	6.0	3.50	7.00	45.5
11	Sassafras sand	5.5	7.00	14.00	190.0
12	Elkton silt loam	4.7	2.87	3.12	23.0
13	Manor loam	5.0	2.00	2.00	18.0
14	Hagerstown silt loam	6.0	0.50	1.00	6.5
15	Manor loam	6.0	2.25	2.25	12.0
16	Manor loam	5.0	2.00	2.00	28.0
17	Frankstown silt loam	5.5	1.25	1.75	14.0
18	Frankstown silt loam	8.0	4.00	4.00	40.0
19	Hagerstown silt loam	7.0	3 25	3.31	18.5
20	Frankstown silt loam	8.5	6.75	7.50	37.0
21	Hagerstown silt loam	6.5	0.50	1.0	7.0
22	Sassafras silt loam	6.3	6.75	8.0	34.0

DISCUSSION

Solubility studies revealed the fact that apatite, which leading soil authors assume to be the most abundant form of soil phosphate, is practically insoluble at pH 5. Further, as the pH value of the extraction solution was decreased from 5 to 4 then 3, the solubility of apatite increased. It was completely soluble at pH 2. Again the phosphorus present in the amorphous and finely divided crystalline phosphates of calcium, magnesium, and manganese, and in the amorphous phosphates of iron and aluminum, was in each case appreciably dissolved at pH 5 and very largely dissolved at pH 2. This is substantiated by the data given in Tables 2 and 3. The pH 5 extractant could therefore be used to differentiate between the phosphorus present in these simple compounds and that present in apatite or compounds of similar solubility. It was found also that in three-quarters of an hour the pH 5 extractant removed practically all the

phosphorus from tricalcium phosphate, from tertiary magnesium phosphate, and from manganese phosphate. One to 2% of the phosphorus present as amorphous phosphates of iron and aluminum were obtained within this time. Tripling the time of extraction, or 2¼

TABLE 2.—*The parts per million of phosphorus extracted from phosphorus minerals by pH 5 and pH 2 solutions.*

The source and treatment of the phosphorus materials studied	Amount per 400 ml of extractant, mg.	The phosphorus extracted from materials: By pH 5 solution, In ¾ hr., p.p.m.	By pH 5 solution, In 2¼ hr., p.p.m.	By pH 5 solution, In 3 hr., p.p.m.	By pH 2 solution in 3 hr., p.p.m.
Apatite:					
(a) U. S. D. A. No. B 15	5.5	1.3	—	1.5	360.0
(b) U. S. D. A. H_2O leached	5.5	—	—	—	—
(c) Quebec	5.5	1.5	—	—	400.0
(d) Quebec H_2O leached	5.5	1.0	—	—	—
(e) Russia	5.5	0.5	—	—	365.0
(f) Russia H_2O leached	5.5	—	—	—	—
(g) Chlorapatite	5.5	2.0	—	2.0	—
Vivianite:					
(a) Penn	5.5	8.0	—	—	285.0
(b) Penn H_2O leached	5.5	0.7	—	—	—
(c) Penn H_2O leached	50.0	—	13.0	19.5	—
(d) Australia	5.5	—	15.5	—	—
Dufrenite:					
(a) Virginia	5.5	—	—	—	—
(b) Virginia	20.0	—	—	—	5.3
(c) England	5.5	0.5	—	—	7.0
Cacoxonite	5.5	—	—	—	5.5
Strengite	5.5	—	—	—	1.5
Variscite	5.5	—	1.8	—	10.5
Wavellite:					
(a) Arkansas	5.5	0.2	—	0.2	5.0
(b) Columbia	5.5	0.7	—	—	—
Fischerite	5.5	2.0	—	—	—
Titanium Phosphate	5.5	17.0	—	—	—
Manganese Phosphate	5.5	360.0	—	—	—
Rock Phosphate:					
(a) Florida	5.5	23.0	—	—	—
(b) Curacoa	5.5	80.0	—	—	—
(c) Wyoming	5.5	5.0	—	—	—

hours, removed double the amount of phosphorus from the amorphous phosphates of aluminum and iron. The pH 5 extractant has made it possible to differentiate between the two following groups of simple phosphates: (A) Amorphous and finely divided crystalline phosphates of calcium, magnesium, and manganese; and (B) amorphous phosphates of iron and aluminum.

TABLE 3.—*The phosphorus removed from phosphorus materials during different periods of contact with the pH 5 solution.*

Weight of 400 ml of extractant, mg	Time of contact with solution and phosphorus removed, p.p.m.			
	¾ hr.	1½ hr.	2¼ hr.	3 hr.
Aluminum Phosphate				
5.1	9.0	19.0	—	—
5.3	11.0	—	—	24.0
10.0	32.5	—	51.5	—
	(47.5)*	—	(126.0)*	—
20.4	—	80.0	—	—
50.0	31.0	—	127.0	—
100.0	—	—	390.0	—
Ferric Phosphate				
5.5	4.0	—	—	8.0
10.0	10.0	—	13.5	—
	(10.5)*	—	(14.0)*	—
23.2	—	30.0	—	—
50.0	25.0	—	38.00	35.0
100.0	—	—	114.0	—
Tricalcium Phosphate				
2.0	—	155.0	—	—
8.0	—	730.0	—	—
4.9	400.0	—	—	—
Tertiary Magnesium Phosphate				
4.3	260.0	—	—	—

*Data on 200-meshed material.

In order to use the pH 5 extractant for this purpose it has been necessary to determine the proportion of the "B" group phosphorus which the pH 5 extractant actually removed from soils by the ¾ hour and the 2¼ hours of extraction. This is on account of the unknown fineness of these "B" group materials as they occur in soils. The proportion of each of these forms of phosphorus removed by the two different times of extraction or the numerical value to give to each period of extraction was calculated from the continuous leaching studies. The data in Table 1 show that the phosphorus extracted by the pH 5 solution in the 2¼ hours period is double the amount obtained in ¾ hour in the case of soils Nos. 6, 10, 11, 14, and 21. This is what would be expected on the basis of the solubility studies if there were no "A" group phosphorus present in these soils.

It might appear from the solubility data, as given in Table 2, that some of the definite crystalline aluminum and iron phosphates were obtained along with the amorphous aluminum and iron phosphates. An example of this would be vivianite. This should be expected to a certain extent because the change from the amorphous to pronounced crystalline structures is probably gradual. The large amount of amorphous phosphorus found in the Sassafras sand (No. 11 as reported in Table 9) might be partly attributed to such an explanation. The data in Table 9 indicate, also, that the group C phosphorus

TABLE 4 —*Phosphorus removed from phosphorus materials and soils by separate 200 ml aliquots of the pH 5 solution every 4 hours*

Consecutive leaching numbers	Phosphorus leached from different kinds and amounts of materials, p p m							
	10 mg aluminum phosphate	10 mg ferric phosphate	10 mg titanium phosphate	10 gr Sassafras soil No 6	10 gr Kevport soil No 10	5 gr Sassafras soil No 11	10 gr Elkton soil No 12	10 gr Hagerstown soil No 19
1	70 0	22 0	100 0	20 5	9 0	29 0	7 5	16 0
2	55 0	11 0	61 0	15 0	10 0	31 0	4 5	16 0
5	56 0	8 5	29 0	7 5	8 0	19 0	5 5	5 0
10	34 0	9 0	24 0	5 0	7 5	16 5	6 0	2 5
15	33 0	7 0	7 0	5 0	7 0	14 0	6 0	2 0
20	29 0	7 0	14 0	3 5	6 5	13 0	6 0	2 0
25	27 0	7 0	9 5	3 0	5 5	9 5	5 5	1 5
30	21 0	7 0	9 5	3 0	4 5	8 5	4 5	1 5
35	18 5	6 5	20 5	3 0	5 0	9 0	4 0	1 5
40	17 0	7 0	9 5	2 5	5 0	8 5	3 5	1 0
45	13 5	8 0	7 5	2 5	4 5	7 5	3 5	1 0
50	10 5	7 0	11 0	2 5	3 0	5 5	3 0	1 0
60	2 5	6 0	5 0	1 5	3 0	4 0	1 5	0 5
70	0 5	6 0	10 0	1 0	2 0	2 5	1 5	0 5
80	—	5 0	8 0	1 0	2 0	3 0	1 5	—
90	—	5 5	9 0	0 5	1 0	3 0	1 5	—
100	—	5 0	7 0	—	0 5	0 5	—	—
120	—	5 0	—	—	—	—	—	—

TABLE 5.—*The phosphorus removed from some Maryland soils by separate 200 ml aliquots of the pH 2 solution every 4 hours after a previous leaching with the pH 5 solution.*

Consecutive leachings	Phosphorus extracted from soils, p.p.m.				
	No. 6 Sassafras sandy loam	No. 10 Keyport loam	No. 11 Sassafras sand	No. 12 Elkton silt loam	No. 19 Hagerstown silt loam
1–4	31.0:36.0	64.0:62.0	95.0:90.0	30.0:30.0	20.0
5–8	17.5:16.3	41.0:40.0	8.5:12.0	5.0: 5.0	21.0
9–12	7.0: 7.5	24.5:24.5	5.0: 5.0	3.0: 3.5	16.5
13–16	5.0: 3.5	20.0:20.0	3.0: 3.0	2.0: 1.5	12.5
17–20	4.5: 5.0	12.5:11.5	1.75:1.25	1.75:1.25	10.0
21–24	—	9.0: 9.5	—	—	8.5
30–60	—	—	—	—	4.0

TABLE 6.—*The phosphorus extracted from three Maryland soils by continuous leaching with pH 2 solution in 200 ml portions every 4 hours.*

Soil used	Consecutive leachings	Average phosphorus content, p.p.m.	Soil used	Consecutive leachings	Average phosphorus content, p.p.m.
No. 19 Hagerstown silt loam	1	160.0	No. 12 Elkton silt loam	1–2	150.0
	2	56.0		3–6	12.5
	3	42.0		7–10	9.0
	4	30.0		11–14	1.5
	5	29.0			
	6	26.0	No. 10 Keyport loam	1–2	264.0
	7	24.0		3–6	98.0
	8	20.5		7–10	30.0
	9	19.5		11–14	14.0
	10–13	11.5		15–18	13.5
	14–17	9.5		19–22	12.0
	18–21	8.5		23–26	9.0
	22–25	8.0		27–30	5.5
	26–29	7.5			
	30–33	6.0			

TABLE 7.—*The total amount of phosphorus leached from pure phosphates and five Maryland soils by the pH 5 and pH 2 solutions.**

Phosphates and soils	Weight of sample leached, gram	Phosphorus obtained by continuous leaching, p.p.m.		
		With pH 5	With pH 2 after pH 5	With pH 2
Aluminum phosphate	0.010	1,393	—	—
Ferric phosphate	0.010	760	288	—
Titanium phosphate	0.010	1,294	572	—
Sassafras sandy loam No. 6	10.0	275	268	—
Keyport loam No. 10	10.0	393	676	1,250
Sassafras sand No. 11	5.0	754	452	—
Elkton silt loam No. 12	10.0	322	164	390
Hagerstown silt loam No. 19	10.0	138	392	590

*Summary of data given in Tables 3, 4, and 5.

or that absorbed on the hydrous oxides of aluminum and iron and that similar to apatite is relatively limited in the majority of the Maryland soils. This is in accord with the work of Robinson, *et al.* (3). It is reasonable to assume, therefore, that any phosphorus material

TABLE 8.—*The arrangement of the soils in the order of their phosphorus nutritional value and in the order of crop responses to phosphorus treatment.*

Nutritional phosphorus or that contained in groups A + 6/11 B plus			Soils arranged in order of		Increase in crop yield for phosphorus %
1/10 C, p.p.m.	1/40 C, p.p.m.	1/20 C, p.p.m.	Increase in nutritional phosphorus, No.	Decrease in crop response, No.	
2.0	1.3	1.5	2	13	——
5.0	1.8	2.6	13	2	3,000
4.0	2.75	3.3	15	15	2,500
3.4	3.1	3.3	14	14	2,400
3.4	3.2	3.4	21	21	2,400
7.2	3.3	4.8	16	16	1,000
6.6	3.0	5.2	19	19	910
5.8	4.25	5.5	17	17	800
8.9	6.43	5.8	7	7	800
6.0	5.10	5.9	12	20	600
7.8	5.92	6.1	9	18	430
9.6	6.90	7.7	5	12	380
12.0	5.80	8.0	18	5	300
15.8	11.33	12.7	20	9	280
15.3	14.7	13.6	6	6	130
15.9	13.0	13.8	3	1	124
15.25	13.69	14.0	4	3	122
16.8	13.6	15.1	22	22	60
33.0	23.0	20.0	1	4	36
23.2	23.0	23.0	8	8	36
25.9	22.2	23.4	10	10	20
74.0	50.0	58.0	11	11	——

more soluble than apatite will have been more completely removed from soils of any maturity. This assumption was substantiated by the results obtained on the Maryland soils. Although the solution data (Table 2) showed that the pH 2 extractant dissolved small amounts of the more insoluble crystalline aluminum and iron phosphates, it is felt that if the material soluble in water had been previously removed the pH 2 soluble phosphorus would have been reduced.

The rôle of absorbed phosphorus or the phosphorus which might be retained by the soil from application of fertilizer was investigated. Hydrous oxides of aluminum and iron which contained 4,000 p.p.m. of absorbed phosphorus were treated with the two extracting solutions. The pH 5 reagent removed none of this phosphorus in 2¼ hours, and the pH 2 solution extracted 2,600 p.p.m. of the phosphorus in 3 hours.

Leaching results, as reported in the condensed form in Tables 4, 5, 6 and 7, show a close relationship between the rate of solution of the phosphorus from the soils and from pure amorphous aluminum phos-

phates by the pH 5 extractant. This is believed to indicate the presence of similar aluminum phosphates in the soils. The large amount of phosphorus obtained by the first few of the pH 2 leachings, following the pH 5 extraction, as shown by the data in Table 5, was taken as indicating that absorbed phosphorus and apatite forms were first dissolved and then the more insoluble phosphates of aluminum and iron were being slowly brought into solution.

FIG 1.—The growth of millet on soils 1 and 3. Y represents no phosphorus treatment and x 1,000 pounds of superphosphate per acre

FIG. 2.—The growth of millet on soil 13 A and b received superphosphate at the rate of 1,000 pounds per acre and c and d no phosphorus

SCHEME OF SEPARATION

The data obtained from the extracting and leaching studies are used for a proposed method of separating the available soil phosphates into three groups. The total phosphorus which can be extracted by leaching at pH 2 within reasonable time can be divided into three groups A, B, and C The A group is comprised of amorphous and finely divided crystalline phosphates of calcium, magnesium, and manganese. The B group is composed of amorphous phosphates of iron and aluminum. The C group is composed of adsorbed phosphorus and of apatite. The following is a simple way of expressing these separations using the letters to signify the respective groups of materials.

1. pH 5 for ¾ hour gives $A + B/11$.
2. pH 5 for 1¼ hours gives $A + B/5.5$.
3. pH 2 for 3 hours gives $A + 6B/11 + C/20$.

These expressions make the estimation of the phosphorus present in each group very simple algebra after the three extractions have been carried on.

TABLE 9 —*The total content of easily soluble (group A), slightly soluble (group B), and less soluble (group C) forms of phosphorus in the 22 Maryland soils calculated from the extraction data and using the proposed algebraic formula*

No	Soil type	The phosphorus content by groups, p p m		
		A	B	C
1	Portsmouth loam	8 00	—	234 0
2	Sassafras loamy sand	1 00	—	10 0
3	Elkton loam	4 25	16 5	28 5
6	Sassafras loam	1 25	22 0	17 5
5	Sassafras silt loam	1 50	8 3	34 0
6	Sassafras sandy loam	—	22 0	33 0
7	Sassafras silt loam	1 63	6 8	35 3
8	Keyport silt loam	—	38 5	4 0
9	Elkton silt loam	1 87	6 8	17 9
10	Keyport loam	—	38 5	49 0
11	Sassafras sand	—	77 0	216 0
12	Elkton silt loam	1 87	2 8	45 7
13	Manor loam	2 02	—	34 0
14	Hagerstown silt loam	—	5 5	7 0
15	Manor loam	2 25	—	19 5
16	Manor loam	2 00	—	52 0
17	Frankstown silt loam	0 75	5 5	20 5
18	Frankstown silt loam	4 00	—	72 0
19	Hagerstown silt loam	3 20	0 7	29 8
20	Frankstown silt loam	6 00	8 3	53 0
21	Hagerstown silt loam	—	5 5	8 0
22	Sassafras silt loam	5 50	13 8	42 0

NUTRITIONAL VALUES OF A, B, AND C GROUP PHOSPHORUS

In the pot tests on the Maryland soils and in the subsequent analyses by the above method, the significance of this method has been clearly demonstrated Considering only the A and B group phosphorus in these soils, it was found that adding only 6/11 of B group phosphorus to A group gave a better order of placing for the soils on the basis of these sums, when compared with the order of placing on the basis of crop responses, than did adding all the B group phosphorus In order to evaluate C group phosphorus nutritionally, various multiples of it have been added to these A + 6/11 B sums and the totals again arranged in descending order of magnitude of the phosphorus extracted These are reported in Table 8 The use of 1/10 of C group places soils 3, 7, 15, 16, 17, 19, and 33 out of the order indicated in crop responses, while taking 1/40 of C group misplaces soils 5, 6, 7, 10, 13, 18, 19, 20, and 22 The use of 1/20 of C group for addition, however, arranged the soils in practically the identical order indicated by crop responses It should be noted that the pH values for soils 18 and 20, as given in Table 1, may account for their relatively high responses, as may related conditions in the case of soil No. 1, a Portsmouth loam

SUMMARY

A method of estimating the different forms of inorganic phosphorus in Maryland soils was developed. It is based upon the rates of solution of phosphate materials and the subsequent ease of determination by the blue colorimetric method. Briefly, this consists in the extraction of soil with two acid solutions which have selective extracting properties. These solutions were sufficiently buffered to maintain their pH values unchanged during extractions of calcareous as well as acid soils.

Solubility studies upon pure phosphate materials and in amounts similar to that found in soils were made to determine the solvent action of these two extractants.

Upon the basis of the data obtained a rapid extraction method was formulated to estimate the phosphorus present in the following three groups of materials: (A) Amorphous and finely divided crystalline phosphates of calcium, magnesium, and manganese; (B) amorphous phosphates of aluminum and iron; and (C) phosphorus absorbed upon hydrous oxides and that present in the form of apatite.

The actual amounts of B and C groups of phosphorus extracted from the soils was arrived at by continuous leaching studies.

Twenty-two representative Maryland soils were analyzed by this method and concurrently tested in pot experiments for response to phosphate fertilizations. This method of analysis placed the soils in practically the same order of phosphorus needs as did the pot tests.

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AVAILABILITY AND FIXATION OF PHOSPHORUS IN HAWAIIAN SOILS[1]

A. FLOYD HECK[2]

THE soils of the Hawaiian Islands have been formed largely through the laterization of volcanic materials. Most of the soils, especially those of the higher altitudes, are of a reddish or reddish yellow color. Some of the lower lying lands and those of a more level topography of higher altitudes or those which have been at one time rather poorly drained are of a darker color and usually contain more organic matter than the red or yellow soils. Most of the red or yellow soils may be classed as laterites or lateritic soils and have a high sesquioxide-silica ratio. Much of the iron and aluminum exist in these soils in amorphous or colloidal forms as the oxides with varying degrees of hydration, and not as crystalline primary minerals as is generally true in most glacial or alluvial soils.

McGeorge (13,14,15)[3] has made rather extensive studies of phosphorus in these soils. As a rule he found their phosphorus content well above that for mainland soils, and yet it many of these laterites there is a deficiency of quickly available phosphorus. He found that the makai (lowlands) lands were usually higher in total and citric-soluble phosphorus than the mauka (highlands) lands. He also reported that low pH values in soils were usually correlated with low availability of native soil phosphorus and seemed to think that lands with less than 40 p.p.m. of citric-soluble phosphoric acid (P_2O_5) might respond to phosphate fertilization. However, little response has been obtained from phosphate fertilization in field tests on these soils even when they were known to be low in available phosphorus.

Recent articles by Hance (7), Ayres (1), and Davis (4) deal with phosphate fixation in Hawaiian soils. Although Ayres has taken water-insoluble phosphorus to mean fixed phosphorus, which may not always mean that the phosphorus is fixed in slowly available forms, his work does indicate that soils in certain districts have a much greater capacity for fixing phosphorus than those in other districts, and that most Hawaiian soils fix large quantities of phosphorus.

EXPERIMENTAL

Beginning in 1930, the writer has made a collection of 100 samples of Hawaiian soils and has used them for phosphorus availability and fixation studies. Since there seems to be a relation between the base saturation and both availability and the fixation of phosphorus in slowly available forms, the pH values were included in this work. The pH values were determined by the colorimetric method known

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[3]Figures in parenthesis refer to "Literature Cited," p. 884.

as the Truog soil reaction test. The quickly available phosphorus was determined by the Truog (17) method modified so as to use a ratio of solvent to soil of 400. The quickly available phosphorus obtained in this way corresponds to the readily available phosphorus of the Truog method except that it is slightly higher.

The capacity to fix phosphorus was determined by a method outlined by the author (10) and is based on the theory that slowly or difficultly available phosphorus is only slightly soluble in 0.002 N sulfuric acid in the ratio used. In this paper the writer is substituting the terms "quickly available" for "readily available" and "slowly available" for "difficulty available", for, after all, availability is very much a matter of rate of solution. The data for pH value, phosphorus availability, and fixation for the 100 Hawaiian soils are given in Table 1.

AVAILABILITY OF NATIVE SOIL PHOSPHORUS

The quickly available phosphorus content of Hawaiian soils is more variable than for most groups of soils. Although the tendency is for the amount of quickly available phosphorus to be generally low, the quantity found in some of these soils is abnormally high. The 100 Hawaiian soils have been grouped according to pH values and the availability of the phosphorus, and these data are given in Table 2.

Forty-six per cent of the soils studied contain 25 p.p.m. or less of quickly available phosphorus and many of these less than 10 p.p.m. or only mere traces. The 20 soils which show an availability of over 100 p.p.m. are either dark, gray, dark red, or brownish in color. This would tend to indicate that organic matter plays a very important rôle in maintaining a high availability for native soil phosphorus. One soil from field 6 of the Hutchinson Sugar Plantation Company has a fixation of 65% and still has 1,100 p.p.m. of quickly available phosphorus. This is a dark-colored soil and contains considerable organic matter which may be responsible for these two seemingly contradictory facts. Perhaps phosphorus in organic combination does not fix as readily as inorganic phosphorus, or is removed entirely from possible fixation.

Relation of pH values to availability.—Investigators have observed a relation between the pH value of a soil and the availability of its phosphorus. There appears to be a more or less definite pH value below which there is a very strong tendency for the quickly available phosphorus content of a soil to be low. Gaarder (6) has shown that 6.5 is the pH value where calcium phosphate has the lowest solubility. At this pH value, phosphorus tends to remain in the soil as calcium phosphate, thus making the availability of the native soil phosphorus greater than if the soil were more acid and the phosphorus could be changed more easily to the less soluble iron or aluminum compounds. At pH 6 the solubility of calcium, aluminum, and iron phosphates are approximately the same, and each of these bases have an equal chance in competition for phosphorus. At this pH value the amount of each of these phosphates formed depends upon the relative amounts of these bases present in a reactive state. At pH 6.5, calcium phosphate has only about one-third the solubility of either iron or alumi-

TABLE 1.—*The pH value, quickly available phosphorus, and the phosphorus fixation of 100 Hawaiian soils.*

Location, description, color, etc., of soil		pH value	Available phosphorus, p.p.m.	Phosphorus fixation %
Hawaii				
Hamakua Mill Co.				
Field 40K	yb*	5.4	14	98.5
Hutchinson Sugar Co.				
Field 6	d	5.9	1100	65.0
Field 15B, Exp 11	d + y	5.6	25	93.2
Kaiwiki Sugar Co.				
Field 31	ry	4.9	22	96.7
Olaa Sugar Co.				
Field 1, 2, 3,	yb	5.6	8	97.0
Paauhau Sugar Co.				
Field 7A	yb	5.7	24	94.5
Field 18	y	6.0	T	98.5
Pepeekeo Sugar Co.				
Field 20	yb	5.6	32	97.0
Kauai				
Grove Farm Co.				
Field 1, line	r	6.4	88	78.2
Field 1, kuakua	r	6.6	78	78.2
Field 4B		6.2	37	89.2
Field 8B-1	yb	5.3	8	94.5
Field 15A	by	5.3	26	83.5
Field 15A	yb	5.6	43	83.5
Field 15C	yb	5.9	21	90.2
Field 15D	yb	5.5	21	91.2
Field 16F, poor	ry	5.2	18	94.5
Field 16F, good	by	5.1	76	97.5
Field 17A, poor	by	5.5	27	90.7
Field 17A, good	by	5.5	40	85.0
Field 20A	by	5.6	45	93.7
Field 20D	by	6.1	30	92.5
Field 25	by	5.1	14	94.2
Field 27, virgin	by	5.1	T	92.0
Field 4A, (makai)	r	6.2	124	77.2

Location, description, color, etc., of soil		pH value	Available phosphorus, p.p.m.	Phosphorus fixation %
Grove Farm Co.—*Concluded*				
Field 17 (middle)	by	5.7	45	90.7
Field 31D (mauka)	d	6.9	152	72.0
Field 31, good	by	5.3	39	92.7
Field 34H	by	6.0	108	90.7
Field Wailua, alfalfa	d	8.0	860	00.0
Hawaiian Sugar Co.				
Field 31	by	6.0	17	83.0
Kekaha Sugar Co.				
Field E, (coral)	rb	8.0	210	35.0
Kilauea Sugar Co.				
Field 1A	by	6.2	88	98.5
Field 2D diseased	d	5.8	56	89.0
Field 4A makai end	ry	5.7	14	94.0
Field 4B line	y	5.8	14	96.0
Field 4B kuakua	y	5.6	56	96.0
Field 15F	by	5.7	51	92.0
Field 18P, very poor	y	5.0	8	98.5
Field 22B	ry	6.2	7	98.2
Field 25B	by	5.3	14	92.0
Field 25C	by	5.3	14	93.5
Field 28A	y	6.2	10	94.0
Field 28C	y	6.8	100	83.7
Field 33½	yb	5.5	9	93.7
Field 35A	y	6.5	20	90.5
Koloa Sugar Co.				
Field 15 (coral)	d	8.0	160	47.5
Lihue Plantation Co.				
Field 1	r	6.4	52	90.5
Field HM10C	rb	6.2	96	89.0
Field HM21		6.0	32	87.5
Makee Sugar Co.				
Field 1B	y	5.4	8	95.5
Field P.L.	g	8.0	12	70.5
McBryde Sugar Co.				
Field 10A	r	5.8	T	86.0

*y = yellow, yellowish; = red, reddish; b = brown, brownish; d = dark; g = gray.

TABLE 1.—*Concluded.*

Location, description, color, etc., of soil		pH value	Available phosphorus, p.p.m.	Phosphorus fixation %
Maui				
H. C. & S. Co.				
Field 8A	br*	6.8	47	55.5
Sample 30	g	8.0	105	21.2
Pioneer Mill Co.				
Field 11—plot P	d	6.9	420	27.5
Field 20	d	6.5	305	36.2
Field 27	d	6.9	215	36.2
Wailuku Sugar Co.				
Field 82	yb	6.4	110	66.2
Field 85	rb	6.3	120	72.5
Field 93	d	6.6	610	40.0
Oahu				
Ewa Plantation Co.				
Sample A	g	7.6	15	79.2
Exp. Sta. H. S. P. A.				
Makiki Station	yb	6.5	700	52.5
Manoa substation (1)	by	5.3	94	94.0
Manoa substation (2)	y	5.1	40	96.0
Waipio Substation				
Plat 15, kuakua	yb	6.3	38	77.0
Plat 15, line	yb	6.1	45	76.7
Honolulu Plantation Co.				
Red Hill (A)	r	6.3	230	57.5
Old soil under parent lava of (A')	ry	7.0	85	46.2
Kahuku Plantation Co.				
Field 1B	d	8.0	22	54.2
Oahu Sugar Co.				
Field 57	r	6.4	94	61.0

Location, description, color, etc., of soil		pH value	Available phosphorus, p.p.m.	Phosphorus fixation %
Waialua Agricultural Co.				
Field Helemano 2A	r	6.2	14	71.0
Field Kawaihapai 3A	d	6.8	395	46.2
Field Opaeula 2A	ry	6.8	63	63.2
Field Opaeula 6	r	6.8	15	64.5
Field Opaeula 16	br	6.4	7	83.0
Field Opaeula 18	rb	5.5	20	79.5
H. S. P. A.—6257	yb	6.8	220	56.2
Waimanalo Sugar Co.				
Field 6	rb	6.1	37	84.7
Field 22B	yb	6.3	78	82.0
Exp. Sta., A. H. P. C.				
No. 25	yb	5.6	6	98.2
No. 555	br	5.5	8	90.0
No. 622	r	6.1	8	84.0
No. 626	y	4.7	5	97.2
No. 631	by	5.0	8	93.5
No. 914	yb	6.1	350	50.0
No. 1591	r	6.4	9	78.2
No. 1594	yr	6.3	5	87.7
No. 1595	yr	5.8	8	81.0
No. 1597	yb	5.7	8	82.5
No. 1599	y	4.8	7	95.5
No. 3128	yr	5.4	10	81.5
No. 3911	by	4.9	6	95.2
No. 5836	rb	6.0	16	83.5
No. 5837	yr	5.8	30	78.0
No. 6459	rg	5.2	T	89.7
No. 10622	g	8.0	190	10.0
No. 10626	g	8.0	95	11.2
M. P. Co. Fld X, El. 2750	rb	5.6	25	96.7
M. P. Co. Fld X, sink at bottom	rb	5.4	30	95.7

*y = yellow, yellowish; r = red, reddish; b = brown, brownish; d = dark; g = gray.

num phosphates, and at this pH value or higher, other factors being equal, the calcium has a distinct advantage in holding phosphorus against the aluminum and iron. This relation seems to be borne out by the data on the 100 Hawaiian soils listed in Table 1. The frequency distribution of these soils, showing the relation of pH value and availability, is shown in Table 2.

TABLE 2.—*Relation of pH value to the quantity of quickly available phosphorus in 100 Hawaiian soils.*

Quickly available phosphorus, range in p.p.m.	Soils below pH 6.5		Soils of pH 6.5 or over	
	Number	%	Number	%
25 or less	41	54.0	5	20.8
26 to 50	17	22.4	1	4.2
51 to 100	11	14.4	5	20.8
Above 100	7	9.2	13	54.2
Total	76	100.0	24	100.0

Of the 76 Hawaiian soils with a pH value below 6.5, 54% have a phosphorus availability of 25 p.p.m. or less, and only 9% are above 100 p.p.m. In the group of 24 soils whose pH values are 6.5 or higher, 54.2% have an availability above 100 p.p.m. On mainland soils, the application of lime in the field practically always increases the availability of the native phosphorus, if sufficient lime is added to raise the pH value to 6.0 or 6.5. This, no doubt, is due in part to a disturbance of the chemical equilibrium in the direction of greater availability and also to the creation of a greater biological balance[4] due to both the lime and the increased availability of the phosphorus in the chemical equilibrium, resulting in an increase in the biological phase of the phosphorus equilibrium as a whole. This is in line with ideas set forth by the writer in a previous paper (12).

Forms of native soil phosphorus.—Soil phosphorus combined with calcium is generally considered to be quickly available, but if combined with iron or aluminum its availability is very much slower. Japanese investigators (16) report finding calcium, aluminum, and iron phosphates in soils in varying proportions. The writer (9) has shown that some soils give positive indications of containing calcium phosphate, while in others the phosphorus is largely held by iron. Many mainland soils show positive evidences of containing calcium phosphate, but most Hawaiian soils, especially those with pH values below 6.5, carry their phosphate mainly in the iron and aluminum forms. Fig. 1 shows the solubility curves for phosphorus of a Carrington silt loam and a soil from Field 18P, Kilauea Plantation, Kauai.

Curve A for the untreated Carrington silt loam indicates a small amount of calcium, together with some rather easily soluble aluminum phosphate. This soil has a pH value of 5.7 and contains 23 p.p.m. of quickly available phosphorus by the extraction method. The triangle

[4]A biological balance may be considered the resultant of biological action in the soil in which nitrogen, phosphorus, or potassium is combined into organic form and is held against inorganic combinations.

abc represents the native calcium phosphate and corresponds rather closely with the amount of quickly available phosphorus. This close correspondence has been found in most soils where comparisons have been made.

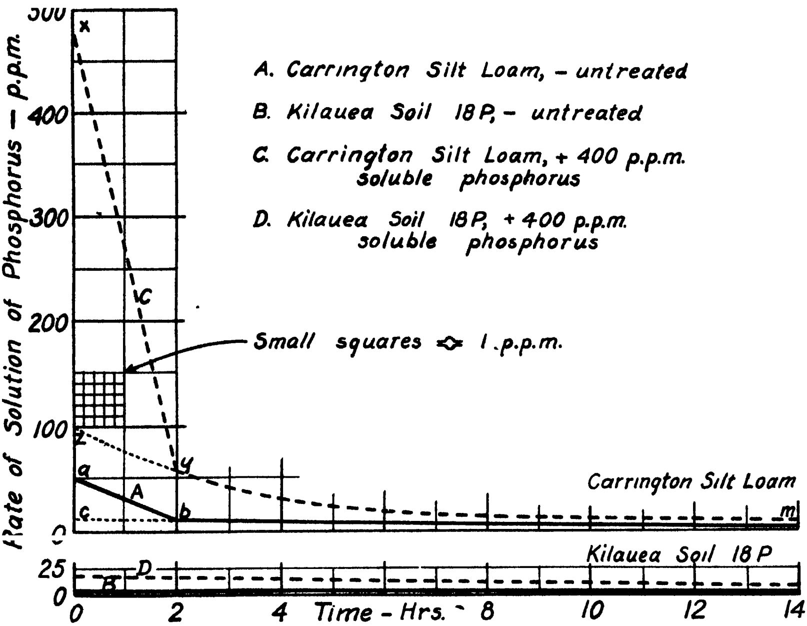

FIG. 1.—Solubility curves for the native and applied phosphates in Carrington silt loam and Kilauea soil, field 18P. The data for these curves were produced by leaching the soils with sulfuric acid at pH 3, and show the rate of solution of the phosphorus. The area under the curves represents the amounts of phosphorus dissolved in any given unit of time.

In curve B for Kilauea soil, field 18P, there is no indication of any calcium or easily soluble phosphates of any kind. The solubility curve indicates that the phosphorus in this soil is practically all in the form of basic iron phosphate, and is of the nature of the phosphorus in dufrenite ($Fe_2(OH)_3PO_4$) (9). This is true of a great many of the red and particularly of the yellow, Hawaiian laterites of the mauka lands. Some of the makai lands, which are more or less alluvial and have a darker color, are usually higher in calcium, have higher pH values, and contain more quickly available phosphorus. Most of these makai soils have a solubility curve for phosphorus which definitely indicates the presence of calcium phosphate, but these soils are comparatively few and nearly all confined to the lower lying lands.

AVAILABILITY OF APPLIED PHOSPHORUS

When phosphate fertilizers are applied to soils, the availability of the applied phosphorus depends upon the form of the phosphorus applied and also on the kind and amount of fixation taking place in the soil. If there is little or no fixation, the availability depends

entirely upon the form and distribution of the phosphorus applied If the applied phosphorus is soluble and takes the form of calcium phosphate, it is quickly available, but if it is fixed as iron phosphate and particularly as the basic iron phosphate (dufrenite), it becomes so very slowly available that to a large extent it may be considered lost to the plant. Phosphorus may be fixed in either the quickly or the slowly available form, but the term fixation in this paper refers to that phosphorus fixed in the slowly available form. The distribution of the 100 Hawaiian soils according to their capacity to fix phosphorus is given in Table 3.

TABLE 3.—*The distribution of 100 Hawaiian soils according to their capacity to fix phosphorus.*

	Percentage of total number
Soils whose capacity to fix phophorus is	
95% or over	19
90% or over	44
80% or over	64
70% or over	77
60% or over	82
50% or over	88
Below 50%	12

Phosphorus fixed in slowly available form.—The amount of phosphorus fixed by soils varies greatly. In the great majority of the laterites, the capacity to fix phosphorus is very high. In this group of 100 soils, 64% fix 80 % or more, 44% fix 90% or more, and 19% fix over 95% of the soluble phosphorus applied. Compared with most mainland soils, this is very high. Of the nearly 200 fixation determinations made on soils from the states east of the Mississippi river, 50% had a fixation less than 40% of the applied soluble phosphorus, and it was the exceptional soil that had a fixation of 90% or more.

Although nearly half of the samples used in this study are from the island of Kauai, there are sufficient samples from each of the other islands to give a rather fair idea of the difference in the capacities of the soils from the different islands to fix applied phosphorus. Even from the limited number of samples available, it is rather easy to see that the soils of the island of Hawaii stand highest in their capacity to fix phosphorus, followed closely by the soils of Kauai and Oahu. The samples available from Maui indicate a much lower fixation for the soils of that island than for those of the other three, but the predominance of dark samples indicates that perhaps these samples are not altogether representative of the soils of Maui as a whole, and that more representative samples would show a higher fixation.

Of the 12 soils having a fixation less than 50%, 11 were either dark, gray, or brown and only one was yellowish in color. This was an old soil, which after its formation, had been covered by a lava flow which perhaps dehydrated some of the iron oxide and rendered it inactive. As a rule, the low-fixing soils are usually dark and quite

often contain lime. These dark soils are, as a rule, not laterites and contain less active iron and aluminum and more organic matter and lime, all of which tend to lower fixation. Although there seems to be a tendency for the presence of organic matter to lower fixation, this does not hold true for the soils on the island of Hawaii. In these soils there is sufficient organic matter to give many of them a brown color, but at the same time most of them show considerable yellow. So it appears that if the hydrated iron oxide is present, it is an active fixing agent even in the presence of enough organic matter to mask its color rather completely.

The figures available indicate that the reddish yellow to yellow soils have the highest fixation of any group of island soils. The soils of Kilauea, Grove farm, and Lihue on windward Kauai nearly all show this tendency. Throughout the figures in Table 1 can be seen the tendency for the yellow in a soil to be correlated with high fixation. This is in accord with the theory that fixation by iron is brought about largely by the hydrated oxides (5), such as ferric oxide monohydrate, or perhaps the dihydrate, should this substance exist in nature. In the amorphous or finely divided state these substances are more or less yellow and tend to impart that color to the soil. However, the red of the hematite and the dark color or organic matter masks the yellow of the hydrated iron and results in a dark high-fixing soil such as is found on Hawaii.

Forms of fixed phosphorus.—The form in which phosphorus is fixed in the soil depends on the nature of the soil and the amount of active iron and aluminum which it contains. If the soil contains sufficient active iron or aluminum, a large amount of the applied phosphorus will be fixed in these forms, but if these substances are low there will be a greater tendency for more of the applied phosphorus to be found in the soil in the calcium form.

Curve C (Fig. 1) shows the approximate amount of phosphorus recovered in the different forms after an application of 400 p.p.m. of soluble phosphorus to a Carrington silt loam. The area of the triangle *xyz* minus the area of the triangle *abc* represents the amount of applied phosphorus recovered as calcium phosphate, and the triangle *zmc* roughly approximates the aluminum or easily hydrolyzable iron phosphate. The balance may be considered basic iron phosphate whose rate of hydrolysis is very slow. In round numbers, with this Carrington silt loam, 43% of the applied phosphorus was found as calcium phosphate, which is quickly available, 34% as aluminum or easily hydrolyzable iron phosphate, and the balance, or 23%, as iron phosphates which are very slowly available.

Miami silt loam is fairly typical of low-fixing soils. In this type it is not uncommon to find as much as 90% of the applied phosphorus in the calcium form, the amount depending somewhat on the pH value of the soil.

The solubility of the phosphorus fixed in the Kalauea-soil, field 18P, is shown in curve D (Fig. 1). In this case no calcium or aluminum was found and only a very small amount of slightly hydrolyzable iron phosphate. By far the greater part of the phosphorus applied to this soil was fixed in the dufrenitic form or basic iron phosphates,

or phosphates of this nature. This is a typical high-fixing laterite (98.5%) and characteristic of many of the phosphorus-deficient soils of Hawaii. In soils like this, the fixed phosphorus is so slightly available that field tests with soluble phosphorus on these soils have usually shown little or no response and the erroneous conclusion has been reached that these soils are not deficient in available phosphorus.

It has been shown (9) that when soluble phosphate is applied with irrigation to the surface of these soils, it is practically imposible to obtain penetration, and the applied phosphorus remains in the immediate surface fixed in forms whose availability is so slow as to render the phosphorus practically unavailable.

DISCUSSION

Because of the low availability of the native phosphorus in most Hawaiian soils, there should be a response to phosphorus fertilization in the field, but with very few exceptions, like those at Pioneer Mill on Maui, this is not the case. In Hawaii, the high surface fixation of the applied phosphorus in very slowly available forms is, no doubt, the outstanding factor responsible for this lack of response to phosphorus fertilizers in the field. In Mitscherlich tests (3), responses have been obtained with Sudan grass from soluble phosphorus used on these laterites, but field tests with cane have not shown corresponding responses. An explanation for this inconsistency may be that in the Mitscherlich tests the applied phosphorus is distributed uniformly throughout the entire soil mass and also that the fixation process requires some time to come to complete equilibrium in the soil. For the latter reason a quick-growing plant like Sudan grass would be able to take advantage of this lag in fixation which might be as much as 20 to 30% for 30 to 60 days, but which a longer growing crop like cane could not do. Another factor which may help to explain the response to phosphorus in Mitscherlich's pot tests is that the sand in the mixture will present surfaces incapable of fixing phosphorus and which hold some phosphorus in quickly available form. In addition, it is doubtful whether responses from Sudan grass would necessarily hold true for cane.

The need for corrective measures to better the phosphorus situation in these soils is indicated in many ways. In addition to its influence on the growth and maturity of the cane, the effect of available phosphorus in reducing the damages by diseases has often been observed. The author (8) has pointed out its apparent relation to brown stripe and eye spot and Carpenter (2) has observed the effect of low phosphorus availability on the ravages of *Pythium* root rot. He says, "Deficiencies of available phosphate promote *Pythium* root rot and growth failure of cane varieties which are not particularly sensitive to increased nitrogen. In root studies with Hamakua soil, H 109, D 1135, and Yellow Calledonia, for examples, were particularly sensitive to the low phosphate availability and resulting root rot."

The facts show that the majority of the Hawaiian laterites are not only low in available phosphorus but at the same time have a high capacity for phosphorus fixation in slowly available form. The practical solution of this problem is not so easy. By liming the soil to a pH

of 6.5 or higher (9, 11), it is possible both to retard the rate of fixation of phosphorus and reduce the amount fixed. The maximum reduction that can be expected from this factor will not exceed 25 to 30% of the applied phosphorus. At the same time there will be a slight increase in phosphorus availability. The advantage from lime could not be very great in these soils, for after liming, most Hawaiian soils would still have a fixation of 60 to 75%.

Placing of the phosphate fertilizer in the line within the root zone would also help as well as the use of phosphates which do not fix so readily. The reverted phosphates have about the same fixation rate as soluble phosphates, but their initial fixation is less and as a result the lag in fixation is greater giving some slight advantage to this form. The phosphorus in rock phosphate, which is mostly Collophane ($3Ca_3(PO_4)_2.nCa(CO_3,F_2,SO_4,O)$), has a very low fixation, but at the same time its availability for cane is also low. Some beneficial effect has been seen when this material was incorporated in the soil with the seed, but as a rule there has been little response.

With the present knowledge of fixation, a combination of the use of a phosphate of lower fixation and an increase in the biological activity in the soil seems to promise the best and most practical solution of the problem. By the utilization of as much crop residue as possible and the proper use of the waste molasses along with phosphorus, the biological activity can be utilized to build up a biological balance and increase the active organic matter in Hawaiian soils so that the phosphorus in rock phosphate or even the native soil phosphorus may be made more available by increasing the biological phase of the phosphorus equilibrium. A phosphate fertilizer combining the non-fixing properties of rock phosphate and the availability of superphosphate used in combination with waste molasses should create a condition in the soil which would tend to increase phosphorus availability.

SUMMARY

This work consists of a study of the availability of native phosphorus and also the extent and form of phosphorus fixation in Hawaiian laterites.

The availability of the native phosphorus in Hawaiian lateritic soils is more variable than in most soils from continental United States. As many as three-fourths of these laterites have a phosphorus availability low enough that they should respond to phosphorus fertilization. Laterites with a pH value below 6.5 are usually low in available phosphorus. Forty-six per cent of the soils reported showed less than 25 p.p.m. of available phosphorus. Native phosphorus in these laterites of low phosphorus availability is largely in the form of basic iron phosphate with a solubility of phosphorus similar to that of dufrenite.

When soluble phosphorus is applied to these laterites, the majority of them fix over 80% of the applied phosphorus in slowly available form. Most of the applied phosphorus is fixed in the soil as the basic iron phosphates, with perhaps some aluminum phosphates. Seldom is much of the applied phosphorus held in these laterites in the form of calcium phosphate.

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INFLUENCE OF PARENT MATERIAL ON SOIL CHARACTER IN A HUMID, TEMPERATE CLIMATE[1]

R. S. STAUFFER[2]

BEGINNING in east-central Illinois and extending on to the northern boundary of the state, there occur certain soils that possess rather undesirable physical properties. Attention was called to these soils in 1915 when a soil survey of Livingston County was being made, and their occurrence in adjacent counties was noted after that time. They were more clearly recognized and described in 1929 when a soil survey of Ford County was being made. Prior to the Ford County work, these soils were not understood, their extent appreciated, nor their significance realized. As a result, soil maps made by the Illinois Soil Survey before 1929 do not distinguish these soils, although they occur in large areas in the whole northeastern quarter of the state.

Since the parent material seemed to be responsible for the properties of these soils, a study of the soils and their respective parent materials was undertaken. The results of a part of this study are reported in this article.

REVIEW OF LITERATURE

That the properties of most soils are influenced, to some extent at least, by the nature of their parent materials has been recognized since systematic study of soils began. In some of the older schemes of classification the influence of parent material was probably over-emphasized. On the other hand, following the interest in the Russian system of soil classification developed in the United States, the tendency for a time was to stress the influence of climatic forces on soil character almost to the exclusion of the parent material influence. It is true that the soil-forming forces of a region tend to produce soils of similar characteristics from materials that are geologically different. As a result, there exist large areas of soils having some characteristics in common which correspond to the great climatic belts. But within such areas the soils may vary widely, and in some cases at least, these variations are due to the nature of the parent material.

The literature contains many references to the influence of parent material on soil characteristics, but most of these references seem to be based on observation alone. Very little work has been reported in which definite studies were made for the purpose of determining how parent material may affect the soil derived from it. There are, however, some outstanding examples of such influence, and a few of these are noted here.

In his discussion of endodynamomorphic soils, Glinka (3)[3] states that the characteristic of humus accumulation in Rendzinas is very striking since these

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[2]Associate in Soil Physics.

[3]Figures in parenthesis refer to "Literature Cited," p. 894.

soils "lie usually in regions in which the external soil-forming forces are not favorable to the accumulation of humus, such as those operating in the Podsol zone."

The soils of the Black Belt of Alabama are commonly interpreted as being an example of parent-material influence. One of these, Houston clay (4) formed from chalky limestone of the late Cretaceous period, is a dark-colored, granular, fairly well-drained soil. Lufkin clay, located nearby but formed from marine clay, is lighter colored, non-granular, very plastic and sticky when wet, and poorly drained.

In glaciated areas where other conditions are very similar, soils vary a great deal because of local differences in the drift. This is well illustrated by the soils of northeastern Ohio. According to Conrey (2), in areas where the underlying rock is shale, and hence there is a relatively greater amount of shale in the drift, the material which forms the soils is a heavy clay. Over the sandstone areas, where sandstone makes up a larger proportion of the drift, the soils have a coarser texture.

PLAN OF THE INVESTIGATION

After some preliminary work, three soil types, all prairie soils, were selected for study. Two of these, designated Clarence silt loam and Elliott silt loam by the Illinois Soil Survey, have very slow subsurface drainage. The other, Saybrook silt loam, is sufficiently open and porous to drain readily.

Both field and laboratory studies were made. The field work included a study of the area from the standpoint of topography, slope, drainage, and nature of parent material.[4]

For the laboratory work, large samples averaging about 15 kilos, were taken by horizons. In every profile at least one calcareous horizon was included, and in several cases, more than one. The deeper samples were secured for the studies on parent material. All samples were taken on very similar slopes of about 1 to 1.5%.

The samples were divided into two fractions by a 2-mm sieve, and the total percentage of the coarser fraction was determined. In the parent materials the lime concretions coarser than 2 mm were separated from the rest of the gravel.[5] The finer fractions were subjected to other determinations, including mechanical analysis, carbonate content, organic carbon, and hydrogen-ion concentration.

DESCRIPTION OF THE AREA

The soils used in this study occur in the Bloomington and Marseilles morainal areas of the Middle Wisconsin Glaciation and are found extensively developed in Ford County, Illinois. The relief of the area is not great, ranging from an elevation of 700 feet above sea level in the northern part of the county to 830 feet in the southwestern part. The change in elevation between these two points is gradual. Due to the presence of low morainal ridges, the surface is irregular but not rough. The principal surface features are a result of the irregular deposition of drift. For the most part, the topography ranges from undulating to gently rolling.

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[4]As used here, parent material includes all calcareous horizons, even though they have been somewhat affected by weathering. These horizons are designated by the letter D.

[5]The term gravel included all particles, except lime concretions, that would not pass through a 2-mm sieve.

This area occupies a comparatively elevated position from which streams radiate in all directions. As a result, no large streams cross the county and no deep valleys occur there. The drainage systems are very youthful and the surface run-off from much of the area does not have ready access to stream channels. However, there is sufficient slope to the surface in most cases that surface run-off passes off readily.

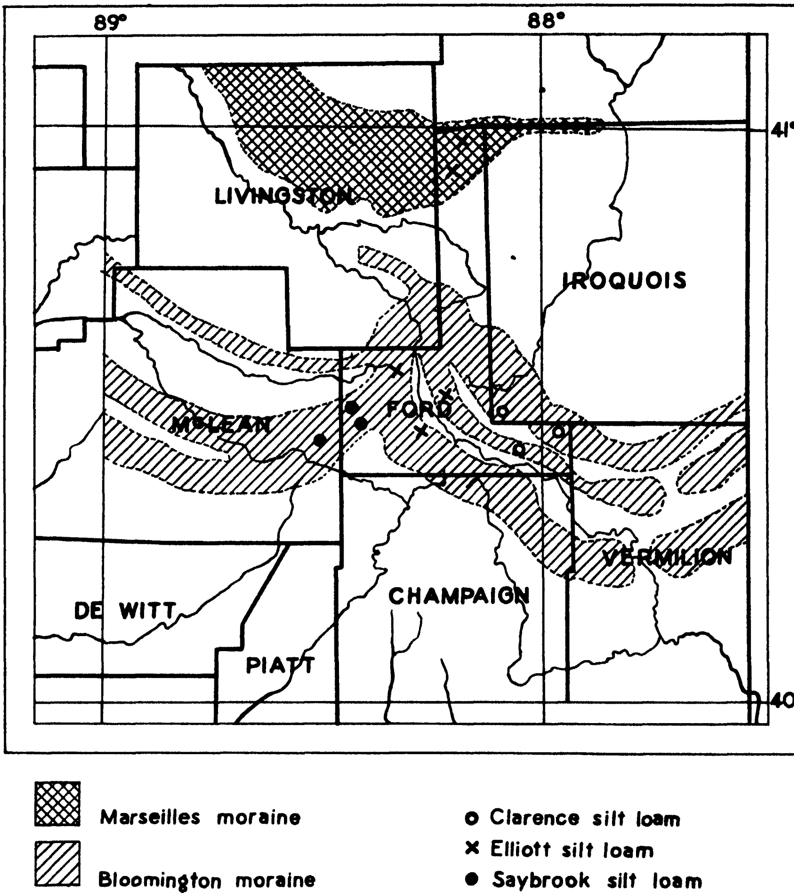

FIG. 1.—Group of counties in east-central Illinois showing the morainal areas and the locations where soil samples were taken.

The area included in this study, no doubt, received some loess, but the deposit is so thin that it cannot be identified with certainty. The drift ranges from 150 to over 200 feet in thickness. West of the re-entrant angle, which occurs in the moraines of southwestern Ford County (Fig. 1), drift contains more sand and gravel and is more open and porous than that of the rest of the county. North and east of this angle, the drift is compact and plastic and does not permit water to

pass through readily. Still further east, much of the drift is so impervious that percolation of water is very seriously interfered with.

The parent material of Saybrook soil is much more uniform in physical composition than that of Clarence or Elliott. In the areas where Clarence and Elliott soils occur, there are many small pockets of gravel and sand which influence the nature of the soils found in the immediate vicinity. There are also small local areas where the parent material contains no gravel, as low as 3% sand, and as high as 70% clay. Such material is very impervious, and where it occurs within 40 inches of the surface, has a decided influence upon the properties of the upper horizons of the profile.

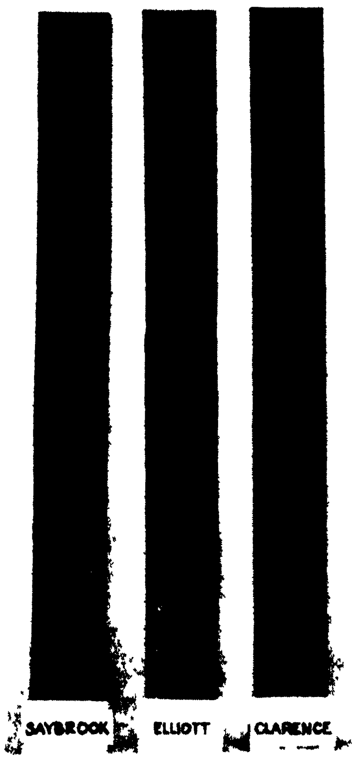

Fig. 2.—Profile samples of the soils included in this study.

The average annual precipitation of this region is about 36, which is usually well distributed throughout the year. The temperature is characteristic of a continental climate and records show it has ranged from 25° below 0° to 110° above. The mean annual temperature for the 10-year period, 1925 to 1934, inclusive, was 52.5°.

DESCRIPTION OF THE SOILS

Fig. 2 shows fairly we'l some of the differences in these soils. The A_1 horizon of Saybrook, which ranges from 8 to 9 inches in thickness, is a friable silt loam, finely granular, and dark brown in color. The A_2 horizon is usually about 7 inches thick and is similar to A_1, but differs physically in being more plastic and lighter in color. The A_3 horizon is a transition zone and partakes of the properties of both the A_2 and the B horizons. The B horizon, usually from 7 to 8 inches in thickness, is only slightly plastic and plant roots penetrate it readily. A distinct C horizon[6], of 3 to 4 inches, is always present. The whole profile shows the influence of good drainage. Even the calcareous drift, which is encountered at a depth of 30 to 35 inches, has a decidedly yellowish cast and is readily permeable.

Clarence soil possesses characteristics of a decidedly different nature. The A_1 horizon, which is commonly about five inches thick, is more plastic and is in a poorer physical condition than the A_1 of

[6]As used in this article, the C horizon is that portion of the soil profile between the B horizon and the calcareous parent material.

Saybrook. The A_2 horizon averages about five inches in thickness, and is only slightly more plastic than the A_1. The A_3 horizon, which is ordinarily about four inches in thickness, is decidedly more plastic than the A_2. The color of the A horizons of Clarence is more gray and less yellow than those of Saybrook. The B horizon, usually from ten to twelve inches thick, is very sticky and plastic when wet, and very hard when dry. Plant roots do not enter it readily, and where characteristically developed, very few roots penetrate the mass. Those that do penetrate this horizon are found chiefly in the cracks or natural cleavage planes. The imperfect root penetration probably accounts for the fact, at least in part, that unless the rainfall is very well distributed throughout the growing season; crops do very poorly on this soil. Usually no true C horizon is discernible, the B horizon passing abruptly into the calcareous material. There is evidence of considerable sheet erosion where this type occurs, even where there is very little slope to the surface. Surface drainage is usually good, but the whole profile shows evidence of poor underdrainage.

Elliott soil is intermediate between Clarence and Saybrook in most respects. It is a better agricultural soil than Clarence, but not as good as Saybrook. The A horizons are thicker and more friable, and the B horizon is not so plastic or impervious as in Clarence. Usually, as in Clarence, no true C horizon occurs in the profile, and although under-drainage is somewhat better, the characteristics of the profile are those of a poorly drained soil.

LABORATORY STUDIES

Since glacial drift is likely to vary quite widely even within small areas, the samples for studies on gravel were carefully selected so as to be as nearly representative of the particular soil type as possible. Further, as mentioned previously, the samples were large so they would be more nearly representative of the material sampled.

The samples were brought into the laboratory and while still moist were put through a 2-mm sieve. The portion that was too coarse to pass through the sieve was washed in distilled water to remove the fine particles. This fine material was thoroughly mixed with the original finer fraction. The whole sample was permitted to become air dry and the percentage by weight of the coarser material was determined.

Since lime concretions are secondary products, and since a considerable portion of the coarser material is made up of lime concretions, these were separated so that a better idea of the nature of the original material could be obtained.

The results of the gravel determinations are given in Table 1.

Mechanical analyses were made of the material that passed through a 2-mm sieve by the method essentially the same as described by Winters and Harland (5). The percentages of total sands and of 5-μ and 1-μ material were determined. These results are also given in Table 1.

In soils as young as those used in this study, the degree of weathering and leaching of the upper horizons of the profile is undoubtedly

TABLE 1.—*Data on the three soil types, Clarence silt loam, Elliott silt loam, and Saybrook silt loam.*

Horizon	Depth, inches	Lime concretions %	Gravel >2.0 mm %	Sands 2.0–.05 mm %	Clay <.005 mm %	Colloid <.001 mm %	pH	$CaCO_3$ equivalent %	Organic carbon %
				Clarence Silt Loam					
A_1	0–5	—	0.1	9.4	38.5	21.0	5.9	—	2.71
A_2	6–10	—	0.6	7.9	40.0	23.0	5.9	—	2.15
A_3*	11–14	—	—	4.0	49.4	33.1	5.8	—	1.03
B	15–25	—	0.4	6.1	63.0	40.5	6.6	—	0.55
D_1	26–32	0.2	1.4	5.5	58.3	36.1	8.0+	14.7	0.38
D_2	33–39	1.7	1.2	5.8	57.8	33.3	8.0+	19.3	0.27
D_3	40–46	0.4	2.5	5.7	52.6	30.1	8.0+	20.3	0.35
D_4*	47–70	—	—	5.6	53.6	30.6	8.0+	20.3	0.31
				Elliott Silt Loam					
A_1	0–7	—	0.4	8.7	38.2	21.1	6.3	—	3.00
A_2	8–13	—	0.4	7.6	41.4	24.2	6.1	—	1.72
A_3	14–18	—	0.8	9.1	48.2	29.6	6.0	—	1.00
B	19–30	—	0.7	8.4	56.4	35.6	6.5	—	0.74
D_1	31–36	0.1	2.9	10.5	46.7	28.5	8.0+	16.4	0.55
D_2	37–45	0.5	5.9†	9.7	44.7	26.7	8.0+	22.5	0.40
D_3	46–56	0.1	3.7	10.0	40.2	23.4	8.0+	23.2	0.46
D_4*	57–70	—	—	12.1	42.3	24.5	8.0+	20.9	0.47
				Saybrook Silt Loam					
A_1	0–9	—	2.00	12.3	34.3	19.2	6.6	—	2.64
A_2	10–16	—	1.3	11.3	37.8	24.5	6.1	—	1.52
A_3*	17–21	—	—	11.8	41.9	29.5	5.9	—	0.94
B	22–30	—	3.4	19.9	44.7	31.3	6.4	—	0.66
C	31–34	—	3.8	24.3	41.7	27.5	7.5	—	0.49
D_1	35–45	0.3	7.7	23.7	31.5	19.6	8.0+	17.0	0.40
D_2	46–52	1.0	7.1	23.9	28.8	16.8	8.0+	22.5	0.36
D_3	53–68	2.1	5.6	24.7	29.5	16.8	8.0+	22.3	0.39
D_4	69–74	0.1	6.4	23.7	29.4	16.7	8.0+	21.2	0.36

*Percentages of gravel were not determined on the A_3 of Clarence or Saybrook, nor the D_4 of Clarence or Elliott.

†One large pebble happened to be in this sample. If it were not included the percentage would be 3.3.

influenced to considerable extent by the nature of their parent material. It seemed desirable to compare these soils with respect to the intensity of leaching, and since hydrogen-ion concentration is probably the most convenient method for this purpose, such determinations were made. The quinhydrone electrode method was used for all determinations, but in order to check the results, determinations on 15 selected samples were made by the hydrogen electrode method. The results secured by these two methods checked very closely, and it was assumed that the results secured by the quinhydrone method were correct.

The percentage of inorganic carbon was determined by a method similar to the one described by Clark and Collins (1) except in two respects. They used a stirrer to keep the acid and soil well mixed, and

continued the aspiration for 5 hours or more for each determination; while in the work reported here, a shaker was used and the aspiration continued for 1 hour. A longer period of aspiration did not seem necessary, because there was no increase in the weight of the absorption bulb after that length of time.

The results in Table 1 are reported in percentages as calcium carbonate equivalent. These figures give some idea of the high percentage of lime in these parent materials.

Since the amount and distribution of organic matter in soils are likely to vary with variations in soil character, the content of organic carbon was determined. The method used is described by Winters and Smith (6). The depths of horizons are also included in the table to show especially the differences in distribution of the organic matter.

DISCUSSION

There is a wide variation in the amounts of gravel in the parent materials of these three soils. Excluding the one large pebble mentioned previously in a D_2 of Elliott, the average percentages of gravel for Clarence, Elliott, and Saybrook parent materials are 1.7, 3.1, and 6.7, respectively. This is approximately in the ratio of 1:2:4. In the upper horizons of the profiles the average percentages are 0.4, 0.6, and 2.6. This is not in the same ratio as in the parent materials, due largely to the fact that the gravel of Saybrook material contains relatively more of the rocks other than limestone. The amount of gravel in the upper horizons of these profiles is quite low for drift-derived soils. This is particularly true for Clarence and Elliott, which do not contain as much as 1% of gravel in any of the upper horizons. There is probably enough gravel in Saybrook to exert considerable influence on its properties.

These soils, as well as their parent materials, differ widely from each other in the percentages of sand they contain. Saybrook parent material contains more than four times as much sand as Clarence and more than twice as much as Elliott. This undoubtedly helps to explain the fact that Saybrook soil permits rapid subsurface drainage, while Clarence and Elliott, but particularly Clarence, are rather poorly underdrained. In the upper horizons the differences in sand content are not so pronounced, but Saybrook soil contains considerably more than the others. There is wide variation in the sand content of the Clarence profile, both between the different horizons of the same profile as well as between corresponding horizons of different profiles, but the Elliott soil averages about 2% more sand than Clarence.

Probably the differences in the amounts of material 5μ and finer are chiefly responsible for the physical differences in these soils. The parent material of Clarence soil averages 55.6%; that of Elliott, 43.5%; and that of Saybrook, 29.8% of 5-μ material. When it is realized that these materials were acid pretreated for the mechanical analyses which reduces the 5-μ material considerably (5), it is readily apparent what a high percentage of clay Clarence parent material contains.

In the A horizons of these soils, the differences in the amounts of fine materials are not so great, but the B horizons show marked differences. Even in the B horizons the differences are not as pronounced as differences in the parent materials. The B horizon of Clarence contains only 8.0% more colloid than the average of the parent material, while Elliott contains 9.8% more than its parent material and Saybrook 13.8% more. This seems to indicate that actual soil development has not advanced as far in Clarence as in the other soils and not as far in Elliott as in Saybrook. This would probably be expected because of the impervious nature of the Clarence parent material.

Fig. 2 shows that soil structure has developed much deeper in Saybrook and Elliott soils than in Clarence. In the field it was frequently noticed that structure particles were apparently developing in the calcareous material of Clarence. No discernible C horizon occurred in the Elliott profile, but structure was not as generally nor as definitely developed in the calcareous material. In the Saybrook profile, the calcareous material was always massive and a distinct C horizon had developed.

As shown in Table 1, the hydrogen-ion concentration of Saybrook soil indicates a more mature profile than that of either Clarence or Elliott, and the Elliott profile shows the influence of soil-forming forces more than does Clarence. The pH of the B horizon is considerably higher in all cases than that of the horizons above. As may be noted in Table 1, this occurs at a shallower depth in Clarence than in the other soils, and yet the A horizons of Clarence show a lower pH than the A horizons of Elliott and Saybrook. It is true that plant roots do not extend as deeply into the Clarence profile as in the other soils, although the organic carbon determinations do not seem to indicate significant differences in the organic content of the deeper horizons of these soils. Whether the organic growth and decay are sufficient to account for the differences in pH of the surface horizons is questionable.

The results of inorganic carbon determinations show that the parent materials of all these soils are highly calcareous, with only small differences between them.

The organic carbon determinations show that the organic matter decreases very rapidly with depth in Clarence.

SUMMARY AND CONCLUSIONS

1. Three soil types, designated Clarence silt loam, Elliott silt loam, and Saybrook silt loam by the Illinois Soil Survey, were studied.

2. Although all these soils have been developed from calcareous, glacial drift of about the same age and have been subjected to very similar climatic and topographic conditions, they differ widely in their properties.

3. The differences in properties are due to differences in the nature of the parent materials.

4. The soils studied are all relatively young, but there are pronounced differences in the stage of development of their profiles. The Saybrook profile shows the most advanced stage of development and Clarence shows the least.

5. There is a smaller amount of gravel in the upper horizons of the profiles than in the parent materials, chiefly because of the removal of calcareous gravel by weathering. There is a relative increase in the amount of gravel in Saybrook because it contains more rocks other than limestone than do the other soils. The parent material of Saybrook contains the most gravel and sand, while Clarence contains the least. Of the material 5μ and finer, Clarence parent material contains the most and Saybrook the least.

6. There seems to be no significant differences between the parent materials in content of carbonates or of organic carbon.

7. Saybrook soil has developed a deeper profile than Elliott, which in turn has a deeper profile than Clarence. This greater depth of the Saybrook profile is due to the greater thicknesses of the A_1, A_2, and A_3 horizons than of the corresponding horizons of the other soils. Both Clarence and Elliott have thicker B horizons than has Saybrook.

8. The shallow profile of Clarence seems to be due to the fact that the weathering forces have not been able to penetrate its parent material rapidly. A large proportion of the fine material, 5μ and smaller, in the B horizon of the Clarence soil is not there as a result of weathering, but because it was present in the parent material.

9. Although there are differences in the A horizons of these soils, the outstanding differences occur in the B horizons and in the parent materials.

10. The data presented here show that where other factors concerned in soil formation, such as age of material, rainfall, temperature, topography, and vegetative cover, are very similar, soils may still vary widely in their properties due to differences in materials from which they are being formed. Further, the glacial drift varies greatly even within short distances, and these differences are reflected in the soils formed from it.

11. This study emphasizes the importance of a knowledge of the parent materials of soils in any system of soil mapping. Such knowledge is a valuable aid in securing consistent mapping over large areas. It further emphasizes the necessity of examining the soil profile to considerable depths, at least through the B horizon, if one is not to be misled by temporary conditions.

12. Parent materials will be responsible to some extent for the characteristics of all except the most highly weathered soils. Young soils may owe their characteristics more to their parent materials than to the weathering forces.

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SOME FACTORS AFFECTING NODULE FORMATION ON SEEDLINGS OF LEGUMINOUS PLANTS[1]

C. A. LUDWIG AND FRANKLIN E. ALLISON[2]

IN a very interesting article by Thornton (12),[3] published in 1929, observations and data are given which seem to show that alfalfa plants (*Medicago sativa* L.), after reaching the age of 2 or 3 weeks, secrete a substance from the roots which markedly stimulates the growth of legume nodule bacteria, and hastens nodule development on young seedlings growing in close proximity. Further experiments indicated that the effect was not due merely to nitrogenous compounds and sugars that may have diffused from the roots. These findings are of considerable scientific interest in connection with the relations existing between root nodule bacteria and their hosts.

Since these observations were reported, the writers have had occasion to carry out experiments dealing with the same phenomenon as well as with a number of other factors which influence nodule formation. Some of the more pertinent of the resulting data are reported below. A portion of the experiments was carried out in the greenhouse, some in an artificially illuminated growth chamber, and the remainder in a modified cold frame. In the case of the cold frame the plants were exposed to direct sunlight in good weather but kept under glass in stormy weather and at night.

The results are reported in terms of the percentage departure of the mean number of nodules per plant of the treated plants from that of the control plants for each day of harvest, the plus sign indicating more nodules and the minus sign fewer nodules on the experimental plants. There are also included weighted means for each treatment, based on total numbers of nodules and plants and covering the entire period of the experiment. The results were also calculated on the basis of percentage of plants with nodules. As the conclusions to which these data lead seem to be identical with those mentioned below, these latter figures are omitted. The number of plants per pot for each day's harvest is not given. It varied somewhat in the different experiments; for soybeans it was 4 to 15 and for alfalfa it was 26 to 82.

The plants considered were not limited to the smaller ones in the cultures since it was not found possible in the present work to make a separation, such as Thornton made, in which the younger plants showed the effect of the presence of older plants and the older ones did not. The effect as noted here, while for the most part of considerably smaller magnitude, was apparently of somewhat longer duration than in the case reported by Thornton.

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[3]Figures in parenthesis refer to "Literature Cited," p. 902.

EXPERIMENTS WITH SOYBEANS (*Glycine hispida* Max.)

SUMMER EXPERIMENTS

The experiments, reported in Table 1, were conducted in the greenhouse, using pots containing 6 pounds of washed, but unsterilized, nitrogen-free quartz sand. The sand was made up to 15% moisture with a nitrogen-free solution of the same composition as that used by Thornton (12). The corn (*Zea Mays* L.) and older soybeans of the summer experiment were planted on July 29 at the rate of 5 seeds per pot. The younger soybeans were planted on August 10 at the rate of 5 seeds per pot where older plants were present and 15 seeds per pot in other cases. All pots were inoculated at the time of planting the younger soybeans with 50 cc per pot of a 5-day culture of soybean bacteria.

The results show that the presence of older soybean plants somewhat favored nodule formation on younger soybean seedlings in agreement with Thornton's observations with alfalfa. Where corn was substituted for the older soybeans, the beneficial effect of the older plants was slightly greater, hence the effect was not specific for legumes. Nitrogen, either in the form of potassium nitrate or of asparagin, was in some cases slightly stimulating to nodule production where added in small amounts but was very inhibitory at higher concentrations. Sucrose markedly favored nodule formation.

FALL EXPERIMENT

The results of a partial repetition of the above experiments, carried out in the greenhouse during cooler weather, is also given in Table 1. In this case the older corn and soybeans were seeded at the rate of 6 seeds per pot on October 10 and the young soybeans at the rate of 12 seeds per pot on October 24. Each pot was inoculated with 50 cc of a soybean culture on October 21.

In this experiment the older soybean and corn plants not only did not favor nodule production on the younger plants but had a harmful effect, more marked in the case of soybeans. Potassium nitrate again decreased nodule numbers except in a few cases at the smallest rate of application. Sucrose favored nodule production but not to quite as great an extent as in the earlier experiment.

The harmful effect of the older plants on nodule formation in the October-November experiment is very probably due largely to the light deficiency at this time of the year, especially for soybeans. The older plants, particularly the soybeans, shaded the younger plants to such an extent as to cause a marked decrease in the size of the seedlings in comparison with those in the controls.

EXPERIMENTS WITH ALFALFA

ARTIFICIAL ILLUMINATION

In Table 2 (1st experiment) are reported the results of tests of the effect of older alfalfa, wheat (*Triticum sativum* Lam.), and corn plants on nodule formation on alfalfa seedlings grown under a bank of 10 Mazda lamps and 1 Cooper-Hewitt mercury vapor lamp en-

TABLE 1.—*Effect of old plants, combined nitrogen, and sucrose on nodule production by soybean seedlings, results reported in percentage deviation of number of nodules per plant from the check.*

Age of plants, days	Percentage deviation caused by										
	Old soybean plants	Old corn plants	Potassium nitrate				Asparagin			Sucrose	
			1 mg. N	8 mg. N	40 mg. N	200 mg. N	8 mg. N	40 mg. N	200 mg. N	1 gm.	10 gm.
					Summer Greenhouse Conditions						
12	+45	— 21	—	—	—	—	—	—	—	—	—
13	+ 8	+ 51	+137	— 3	+21	—84	+ 26	+11	—74	+ 79	+384
14	+15	+102	—	—	—	—	—	—	—	—	—
16	+54	+ 86	+ 26	— 3	—65	—97	+ 2	0	—98	+203	+ 85
18	—	—	+ 78	+59	+15	—96	+123	+35	—69	+108	+ 37
20	—14	— 8	— 14	— 6	—46	—94	— 20	+24	—82	+ 22	— 31
23	—	—	+ 3	+25	— 8	—95	+ 31	+28	—93	— 21	— 12
Mean	+12	+ 36	+ 22	+20	—23	—96	+ 30	+24	—83	+ 47	+ 14

Late Fall Greenhouse Conditions

Age of plants, days	Old soybean plants	Old corn plants	Potassium nitrate				Sucrose		
			5 mg. N	25 mg. N	100 mg. N	200 mg. N	1 gm.	5 gm.	10 gm.
15	—31	— 11	+ 11	—11	—74	—78	+56	+ 4	+ 4
16	—53	— 64	— 14	—35	—59	—79	+ 7	— 3	+ 4
18	—58	— 31	+ 11	— 5	—73	—63	+36	+ 67	+ 29
21	—46	— 17	+ 28	— 8	—49	—62	+ 3	+ 39	+ 17
25	—63	— 29	— 35	—23	—38	—72	+21	+ 6	+ 29
Mean	—53	— 29	— 2	—15	—54	—70	+20	+ 24	+ 20

closed in glass (light intensity about 2,000 foot-candles), using a 12-hour daily period of illumination. The experiments were carried out in glazed pots holding 4.5 kg. of washed sand. After addition of the Thornton nitrogen-free nutrient solution, the pots were sterilized in the autoclave and planted with sterilized seeds. The wheat, corn, and older alfalfa seed were planted 14 days before those of the younger alfalfa. The cultures were inoculated with 10 cc of a 4-day culture of the alfalfa strain of nodule bacteria either at the time of planting the younger plants or a week earlier, as shown in the table.

After making allowance for the wide variations always so pronounced in experiments dealing with nodule numbers, the data show only a slight effect of the older plants. The time of inoculation, likewise, had a negligible influence.

COLD FRAME EXPERIMENT

In the second experiment, reported in Table 2, the methods used were similar to those used in the first experiment except that the pots were kept in a modified cold frame. The older plants were seeded on August 28 and the young alfalfa 2 weeks later. Some of the young alfalfa plants were inoculated by the addition of 10 cc of bacterial culture per pot; the others received seed inoculation only. Two samples of quartz sand were used, one merely washed, the other heated at about 425°C for 18 hours to destroy organic matter. The latter was a finer grained sand than the former.

The number of nodules produced (not shown in the table), although somewhat variable in some cases, showed very strikingly that the addition of a heavy inoculum increased the speed of nodule production and the number of nodules per plant.

Under both conditions of inoculation the older plants produced a favorable effect on nodule production in the majority of cases. In general, this effect was small but in the heated sand it was very marked, the mean effect being about three-fold. These figures are a very definite confirmation of the effect as reported by Thornton.

SAND EXTRACT EXPERIMENT

In another experiment, alfalfa, corn, and wheat were planted thickly in separate jars of sand containing 3 kg. of sand each. On the eleventh day after planting, the sand was carefully removed from the roots and extracted with cold water until about 1.5 liters of extract for each treatment and for an unplanted control had been collected. These extracts, after sterilization in the autoclave, were added, together with actively growing nodule bacteria, to cultures of alfalfa seedlings at the rate of 15 cc of extract per culture, each culture consisting of the seedlings from 100 seeds planted in 4.5 kg. of sand. An 18-hour daily illumination period with artificial light was used.

On the seventh day after seeding, an average of about 1.5 nodules per plant had formed and most of the seedlings had the first leaf fully opened. The extracts from the sand in which the plants had grown gave essentially the same effect as the plain sand extract. Incidentally, laboratory tests of these extracts, including that of the

TABLE 2.—*Effect of old plants on nodule production by alfalfa seedlings, results reported in percentage deviation of number of nodules per plant from the check.*

Age of plants, days	Percentage deviation caused by the presence of old plants												
	1st experiment*						2nd experiment†						
	Sand inoculated 1 week before planting			Sand inoculated at planting			Seed, only, inoculated			Sand inoculated with a heavy inoculum			Seed, only, inoculated, heated sand
	Alfalfa	Wheat	Corn	Alfalfa	Wheat	Corn	Alfalfa	Wheat	Corn	Alfalfa	Wheat	Corn	Alfalfa
7	—	—	—	—	—	—	—	0‡	—	−41	+60	−64	+1168
8	−15	−67	−59	−50	−19	+81	+ §	—	+ §	+134	+195	+46	+177
9	+92	+18	+77	−12	−41	+19	−31	+36	+54	+139	+65	+7	+500
10	—	—	—	—	—	—	+176	+283	−100	—	—	—	—
11	+1	+1	+65	+48	−13	+30	—	—	—	—	—	—	—
Mean	+29	+9	+55	+30	−17	+26	+31	+104	+70	+82	+99	−17	+291

*Artificial illumination used.
†Modified cold frame used.
‡No nodules on either the check plants or those grown with older wheat.
§No nodules on the check plants, but 0.01 and 0.07 nodule per plant on the plants grown with older alfalfa and corn, respectively.

sand in which plants were not grown, showed that the growth substance (3) required by these organisms was present in sufficient quantity in all cases to permit good bacterial growth.

DISCUSSION

The data presented here show that nodule formation on seedlings may be favored by addition of sucrose, by applying especially large numbers of active organisms, and sometimes by the presence of older legume or nonlegume plants. Small quantities of available nitrogen may occasionally be slightly beneficial but larger quantiti retard nodulation.

These findings with respect to sugar and nitrogen are in general agreement with earlier work discussed elsewhere (2, 4); likewise, the favorable effect of heavy inoculations in hastening nodule formation is a commonly observed (13) phenomenon, even though the total number of nodules that will form is small in comparison with the number of bacteria added.

In considering the data dealing with the effect of older plants on nodule formation it is advisable to disregard the results of the fall experiment with soybeans because the harmful effect of the older plants on the smaller ones was due chiefly to shading. A summation of the remaining results shows 33 positive and 15 negative results (69% positive). Where the older plant was a legume the effect was 70% favorable; where a nonlegume the figure was 68% positive. If each experiment is considered as a whole (mean value of all the harvests of a given treatment), the number of positive values totals 13 and the negative ones 2 (87% positive). That a stimulation of nodule production by the presence of older plants with experimental ones did occur seems without question to be shown by these data. On the other hand, the effect did not appear with much consistency and in most cases was much smaller than that observed by Thornton. Only in the last experiment where a finer, heat-treated sand was used was the result comparable with his. It should be borne in mind that in Thornton's experiments, as well as in ours, the plant culture medium contained neither nitrogen nor sugar and hence was very unfavorable to the maintenance of the added bacteria in an active growing condition. Using a very different experimental technic (agar cultures), Lohnis (6) was unable to obtain any effect of older plants on nodule formation on clover seedlings.

The time required for the first nodules to form in our experiments with alfalfa was usually 7 to 8 days as compared with about 10 days in Thornton's experiments. Allowing 3 days for germination, nodule formation under our conditions occurred in 4 to 5 days after the first root hairs formed which according to Thornton and others, is about the minimum time possible. Obviously, the more rapidly nodules form on the control plants, the less opportunity for detecting nodule stimulation by any treatment. Incidentally, in these experiments nodule formation on alfalfa seedlings usually occurred at about the time of the opening of the first true leaf, as observed by Thornton. This is probably largely a coincidence, since nodule development is now known to depend largely upon the carbohydrate-nitrogen rela-

tionships (1, 2, 4, 5). If these relationships are satisfactory it apparently requires about the same length of time for the first nodules to develop as for the first true leaf to open.

The most probable explanation for the beneficial effect of the older plants (where observed) seems to be the favorable effect of plant roots on bacterial growth. The experimental results reported here are consistent with this idea. Roots may give off at least traces of nitrogen and of organic substances. There is also a constant sloughing off of organic material due particularly to the death of root hairs. In addition, the pH (10) immediately surrounding the roots may be more favorable for bacterial growth. These influences of roots on bacterial growth have been considered rather fully by other workers (7, 8, 9, 10, 11). Our results showing much greater effects in heated sand, where coenzyme R (3) could not have been present, than in unheated sand, where a laboratory assay showed it present in adequate amounts for good bacterial growth, suggest that this growth substance may also play a very large part in the effect of the rhizosphere.

Thornton's results, showing that an extract from sand in which older plants had grown both favored nodule formation and bacterial growth on nitrogen-free sucrose agar, are also pertinent. A portion of this improved growth must be attributed to the traces of nitrogen added in the extract, but in addition, it certainly contained coenzyme R, which is essential for the growth of alfalfa bacteria. This substance is abundant in green and dead plant materials and is present to some extent in soil and sand. Thornton suspected that the effect was due to an amino acid but pot experiments with asparagin gave negative results.

The beneficial effect of the older plants in Thornton's experiments apparently lasted for only a day or so and hence the phenomenon would seem to be chiefly of scientific rather than practical interest. Even this slight effect, observed only in very pure sand, would probably not be detectable in an ordinary cultivated soil containing organic matter and other food for bacterial growth.

SUMMARY

1. The effect of the presence of older plants, including alfalfa, soybeans, wheat, and corn, on the nodulation of either alfalfa or soybean seedlings growing in close proximity was studied in sand cultures. Under conditions where the light intensity was not limiting, 33 positive and 15 negative results were obtained. The percentage of positive results was approximately the same whether the older plants were legumes or non-legumes. This beneficial effect of the older plants did not appear with consistency and in most cases was much smaller than that observed by Thornton in his work with alfalfa.

2. In similar experiments, where older plants were not present, increased nodulation followed additions of sucrose and of a heavy inoculum. Small quantities of available nitrogen were sometimes slightly beneficial but larger quantities greatly depressed nodule formation.

3. Cold water extracts of sand in which alfalfa, corn, and wheat seedlings had been growing, produced no appreciable effect on nodule formation when added to cultures of alfalfa seedlings.

4. A logical explanation of the favorable effect of older plants on nodule formation seems to be the extreme favorableness of the rhizosphere to bacterial growth, this in turn being due in part to the liberation of the essential bacterial growth substance from the roots.

5. The practical importance of this effect under field conditions is probably negligible.

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EVIDENCE OF FIELD HYBRIDIZATION IN BEANS[1]

W. W. MACKIE AND FRANCIS L. SMITH[2]

SINCE Johannsen's classical demonstration with the Princess bean in 1903 (8)[3], the fixity of pure lines from single selections has been largely taken for granted. The breeders of beans in both Europe and America who have resorted to artificial hybridization have, however, found that beans do not always remain fixed (9). Pearl and Surface (11), in Maine, working with yelloweye beans, found that it was necessary to grow the parental stocks in cages for several years to be certain of their purity. Emerson (2), in his studies of heredity in common bean hybrids in Nebraska, found cross-pollination which varied from 0 to 10%. Kristofferson (10) recorded cross-pollination amounting to 0.8% in snap beans and 1.42% in field beans. However, many varieties did not show evidence of cross-pollination even after being exposed for several years. Hardenburg (5) believes that hybridization in the bean fields of New York is of no commercial importance. Kooiman (9) cites a number of European and some American references to field hybridization in common beans. Without exception, the bumblebee is charged with the formation of the field crosses.

The evidence of field hybridization in California bean fields is spread over six species of beans grown in the state, namely, (a) common beans (*Phaseolus vulgaris*), (b) tepary beans (*P. acutifolius*), (c) blackeye cowpeas (*Vigna sinensis*), (d) *Multiflorus* or butter beans (*P. coccineus*), (e) small or baby lima (*P. lunatus* var. *Sieva*), and (f) large lima (*P. lunatus* var. *macrocarpa*).

Common beans were first introduced into California through the Spanish missions and have been grown without interruption ever since. Other species and varieties have been added from time to time (7). The conditions of climate and soil in California are adapted to a wide range of bean varieties. These advantages have placed her usually in the first rank in yield per acre and in the value of the crop, due to the superior prices of the lima beans, which are protected by a natural climatic monopoly. The situation is ideal, therefore, for observations on the occurrence of field hybridization.

On the coast, in regions south of Monterey Bay, Small Whites are grown almost exclusively in certain areas, like Salinas and Lompoc. In the fields near Salinas some years ago the Michigan Robust pea-bean was introduced. From this lot a field hybrid, apparently with California Pink, was isolated. The resulting hybrid plants presented a wide range in seed color (white, pink, brown, and black, with all intermediate grades), maturity, yield, and climatic adaptation. From the vicinity of Lompoc black and colored seeds have arisen in fields of Small Whites. These also have shown a wide range of characters. Among the colors, black and pink predominated. Pods

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[3]Figures in parenthesis refer to "Literature Cited," p. 909.

of normal types and blue pod types occur. The shape of this hybrid seed varies widely. From one of these arose the variety known as "Very Small Pink," the smallest seed of all varieties of common beans which we have observed.

At King City, in the interior portion of Salinas Valley, the California Pink bean is principally grown, owing to climatic adaptation. The Pink bean from this area commands a higher price due to superior quality. A request from farmers of this area to improve the yield and disease resistance of the Pink bean led to field selection of about 100 plants, all bearing Pink beans. These plants were then grown in plant-to-row tests in the following year at three places of widely different climates, *viz.*, Davis, Berkeley, and King City. Over 15% were found to be heterozygous for such factors as color, size, and shape of seed and disease resistance. Among the homozygous or fixed lots, a wide variation from the commercial ideal of the Pink bean appeared. In color, the variation ranged from brown to pale pink, lavender, and red. The size varied from an index of 26.3 to 42.8 when the normal Pink averaged about 33. (The index is the weight in grams of 100 average beans.) The shapes included cylindrical, oval, and very flat, and were widely different from the standard type for Pink beans. Resistance to Rhizoctonia, Fusarium dry rot, and charcoal rot varied as widely. In time of maturity the range extended from very early to very late. Some selections were so late that they failed to mature a crop. In yield, the lots varied from 580 pounds per acre for the poorest to 3,840 pounds per acre for the highest, with an average for the Pink checks of 1,890 pounds per acre. At King City the yields ranged from less than half that of the surrounding field to more than 50% greater, but the average yield for the selections averaged almost exactly the same as for the field from which they were taken. Only 30% of the selections were retained for further study, and certainly no more than five or six of them deserved further recognition as commercially fit. However, among the survivors a combination of high yields, satisfactory color in seed, and disease resistance superior to the present standard is assured.

Red Kidney beans grown in New York and Michigan are annually injured by various diseases, including anthracnose and a number of bacterial diseases. These apparently cannot exist under the climatic conditions of the Sacramento Valley, where this type of bean is principally grown. Sacramento seed is therefore in demand in New York. Seed from fields rogued for viny types and mosaic plants, when sent to eastern markets, showed off-types in the seed, which caused the rejection of certain lots. These off-type beans were selected out and planted. A wide range of fixed and heterozygous plants appeared at harvest. Of these 112 off-type selections, 22% proved heterozygous. Heterozygous lots for seed color comprised 14% and included red, pink, brown, black, white, and mottled. Judging by the characters represented in the seed and vines, the parents must have included Red Kidney, Mexican Red, Pinto, Large Whites, and other varieties. The viny types, which represented mainly field crosses between Red Kidney (a bush) and Mexican Red (a vine), comprised 9% of the heterozygous off-types. Size and shape of seed varied

widely, the size indexes ranging from 29 to 71.4. Roguing did not remove completely these objectionable plants which usually bore off-type seed, because heterozygous plants could not always be distinguished from the regular Red Kidney bush, which is more like an upright vine than a typical bush in appearance. Many regular bushes, among them hybrid stocks, bore seed like Mexican Red and further complicated the purification by field roguing. This seed, although sent from the West, originally came from New York, hence part of the field crossing at least occurred under New York conditions, which indicates that this condition is worse in New York than Hardenburg (5) suspected. This contention is further supported by the appearance in these hybrids of bean types resembling the Magpie variety, grown only in New York. Continued roguing for 3 years has, however, so improved the purity of seed that it is now very difficult to find viny and off-type plants. Plant selections fixed for desirable qualities have been secured, as has been done with the California Pinks.

About 5 years ago (1930), a farmer in Sutter Basin found an early maturing vine in his Pink beans. The seed from this selection is now being grown in the Sacramento Valley under the name Early Pink. Plant selections from this lot have been tested for fixity and many plants heterozygous for size and color have been found. Off-type homozygous strains for these same factors render the variety as now composed undesirable by the trade, although its earliness and high yield appeal to the farmer.

MEASURES OF FIELD HYBRIDITY IN COMMON BEANS

In the plats at Berkeley 60,000 plants were grown in 1932, 8 of which proved to be field hybrids, or less than 0.013%. The F_1 hybrid of Robust, a white-seeded pea-bean, and California Pink is brown-seeded. In 1932 Robust and Pink were grown in adjacent rows. Seed from Robust was planted in 58 rows in 1933. Any brown-seeded plants would be F_1 hybrids and their number would be a measure of field hybridization between the two varieties the year before. Among 3,955 plants not a single brown-seeded one was found.

Both self color and mottled colors are dominant over white in the F_1. In 1933 pure white varieties were grown adjacent to colored ones. Seed from these white varieties were grown in 1934. All colored beans appearing among these were obviously field hybrids. The results obtained are shown in Table 1.

Field crossing in the 4,136 plants counted and observed was 50 plants, or 0.73%. These field hybrids are doubtless the result of crossing due to pollen carried from one row to another by adult thrips and appear to be a very reasonable measure of normal California field hybridization between adjacent varieties of common beans maturing at approximately the same time. That similar crossing occurs between individual plants within the variety may be assumed. Such hybrids may be detected by variations in the date of maturity, size and shape of seed, yield, disease resistance, and similar characters.

The tepary bean (*Phaseolus acutifolius*), an indigenous bean of the Arizona and Sonora regions found by Freeman (4) in cultivation by

the Pueblo Indians of the Southwest, frequently crosses in the field, breaking up into all the usual color segregations found in the common bean. No field or artificial crossings have been secured between *P. acutifolius* and *P. vulgaris*, although such crosses have been attempted for 15 years.

TABLE 1.—*Percentage of natural hybridization in white-seeded beans, 1934.*

Variety	No. rows counted	Total no. plants	No. plants white	No. plants colored	% colored
Robust	31	2,143	2,130	13	0.61
Bluepod	9	483	477	6	1.24
Great Northern	2	102	102	0	0
Hungarian	1	77	77	0	0
Kotenashi	5	273	271	2	0.73
Large White	1	78	78	0	0
Michigan Pea	1	51	51	0	0
Small White	2	223	223	0	0
White Kidney	5	367	367	0	0
F_3 White, Pink x Robust	8	402	399	3	0.75
F_3 White, Pink x Large White	3	140	137	3	2.14
F_3 White, Pink x Great Northern	14	618	614	4	0.65
Total		4,957	4,926	31	0.63
Total from White F_3		1,160	1,150	10	0.86

Blackeyes (*Vigna sinensis*), although cowpeas, are classified commercially as beans. Artificial crosses between Blackeye and self-colored or mottled cowpeas yield black F_1 seed. Such seed has been recovered from a Blackeye field at the Riverside Citrus Station in a heterozygous condition. In Merced County, a field hybrid, evidently a cross between Iron and Blackeye, was found also in a heterozygous condition. Brabham seed likewise yielded hybrid seed in a heterozygous condition. At Modesto brown self-colored cowpeas have been found in Blackeyes, evidently having arisen from intercrosses among the Blackeye plants. This last type appears more frequently than the other forms mentioned.

Small or Baby limas (*P. lunatus* var. *Sieva*) throw commonly the so-called viny mutations or sports. One of these selected from the Henderson Bush gave rise to the Wilbur variety, a superior yielding viny type which has since remained fixed. Many of these viny "mutants" break up into vine and bush types, usually in a 3 to 1 ratio. Others break into bush and vine at different ratios, indicating different factors for vininess. In these heterozygous types Mendelian segregations occur in shattering, maturity, and stature of vine. Colored beans occur occasionally from these field crosses, usually represented by mottled brown and red seed. The small lima bean grown by the Hopi Indians of Arizona for centuries shows constant field crossing represented by a wide range of color variation from white to black, including many colored mottles. Heterozygosity is also expressed in plant stature, disease resistance, and maturity. From this stock selections were obtained for use in successfully

breeding for the disease-resistant Hopi varieties now grown in areas where nematodes and Fusarium dry rot limit the production of Small lima beans.

Large lima beans (*P. lunatus* var. *macrocarpa*) include a large number of horticultural varieties, all of which have arisen from field selection. From fields of Large limas in Santa Barbara, where they were first introduced, a number of so-called "mutants" have been found, including willow-leaf, mottled, and red. Red beans rather frequently arise in Large limas, and although such red seed is all removed by hand picking, it arises again and again. Tests with this seed show it to be mainly in a heterozygous condition, usually breaking into red and white in a 3 to 1 ratio. A reverse ratio is also found, indicating the possibility of a dominant as well as a recessive white. This condition is being studied.

Fordhook, Burpee's Bush, Burpee's Improved Bush, and other Large lima varieties are grown by farmers for seedsmen under contract. The roguing of vines from these bush types is included in every contract. It is presumed that such viny types are rogues arising from admixtures during planting, threshing, and recleaning. Selections of such viny types tested in plant to row proved most of them to be field hybrids, which broke up into vine and bush types, usually at the rate of 3 vines to 1 bush. Wide variations from this ratio occurred, indicating the possibility of more than one factor for vininess. In some of these field hybrids the potato or round type of seed occurs, usually as a recessive which breeds true and may be borne by either bush or vine.

The evidence just presented includes types which are easily recognized, but the more important factors involved in these field hybrids which control quality, vigor, and hardiness in vines are usually overlooked. The plan started in 1930 for improving the Large lima bean included plant selection among the six best varieties found in the principal Large lima bean areas. These varieties were selected and re-selected for vines showing superiority in yield, early maturity, vigor, Fusarium resistance, and seed quality. Great variation was found, especially in size, color, and shape of seed. The size as measured by the index ranged from 44 to 177, or 400%, within one variety. This condition was found in all the older varieties, but to a lesser extent in those varieties of more recent origin, as might be expected. The Large lima bean is identified by radiations which extend fan-shaped from the hilum toward the dorsal edge. These radiations are darker colored than the rest of the seed coat. If they are wide and dark, the bean is given a dull, dingy, or gray cast, which detracts from its appearance and its marketing quality. A bright white bean with a slightly greenish case is desired. Yellowish tints in the seed-coat or a lack of brightness detract from marketable quality. Pits, or dimples, which are not found in Small limas, cause seed to look shrunken if too large. Twists or distortions of the seed are likewise undesirable. Transverse splitting of the seed coat due to weakness at the micropyle permits moisture and fungi to enter with corresponding damage to germination and quality. All of these characters are inherited and are therefore subject to control by breeding methods.

Among the 269 plant selections tested from 6 standard varieties of Large limas, over 14% were found to be heterozygous for one or more of the characters just outlined. More than 4% of fixed selections were found combining all the desirable characters sought.

Multiflorus or butter bean (*P. coccineus*) includes such varieties as the Scarlet Runner and Aztec and marks a strict departure from the other five species just considered because it must be insect cross-pollinated in order to fruit fully (6, 9). When colored and white varieties are placed adjacent, crossing invariably shows with the normal Mendelian segregations found in other beans.

INSECT POLLINATION

Field hybridization in beans is charged by practically all investigators to the bumblebee. Other insects, usually the honey bee, are added. To check this under California conditions, the senior author watched carefully for many hours daily bumblebees and honey bees, gathering nectar from bean flowers, especially the Large lima. In no instance did he observe either of these insects forcing open or tearing open the flowers of beans which had not already opened naturally. It is well known that all bean anthers spill pollen for a considerable period before the flowers open. Pollen grains begin to germinate 4 or 5 hours before pollination actually begins (12). The pollen tube enters the micropyle of the ovule within 8 or 10 hours after pollination occurs. The rapidity of these processes indicates that foreign pollen transplanted on the receptive stigma of the bean flower would be at a disadvantage in the race to enter the ovule in the process of fertilization. Unless the pollen tube of foreign pollen grows more vigorously, causing its nuclei to out-travel those of the flower's own pollen tube, it appears unlikely that bumblebees or honey bees could cause cross-pollination. That pollination from two sources at least may fertilize ovules in a single flower, we have demonstrated in artificial crosses. One such cross between a white-seeded female and a pink male yielded four seeds in the single pod. These seeds in the F_1 gave 3 colored and 1 white plants. The white seed arose, of course, from pollen spilled from the anthers of the white female flower at the time the artificial pollination was made. As we always pollinate immediately after emasculation, the two types of pollen had equal opportunity to fertilize the ovules.

Further studies of agents which might cause field cross-pollination showed the presence within all bean flowers in all bean areas of the state of a small but extremely active thrips, which was identified (3) as the western grass thrips (*Frankliniella occidentalis*). This thrips is not to be confused with the common bean thrips (*Hercothrips fasciatus*) which feeds on the leaves. The western grass thrips feeds on the flower parts, including the nectar and pollen, and is able to pierce the keel and attack the sexual parts. So numerous are these active little insects that several may be found inside a single bean flower. Competition causes them to drive one another out. Attached to their bent legs and to their bodies may be seen many pollen grains which are carried away with them in flight or otherwise. As vines

are usually intertwined about one another, the thrips may readily carry pollen to the flowers of another vine. In contrast to the bees, the thrips usually enter a flower bud before the flower opens and can readily effect pollination before the anthers of the flower spill their pollen (1). That this early pollination may be effective we have proved repeatedly in artificial crossing when the anthers are removed green before any spilling of pollen occurs. The work of the western grass thrips (*F. occidentalis* (Pergande)) appears to us to be responsible for field hybridization in beans. This accounts for the large proportion of intervarietal crosses and the lesser number of crosses between varieties. These conditions in bean fields emphasize the need of planting and maintaining seed of strict varietal purity.

CONCLUSIONS

From the evidence presented, field hybridization in all six species of beans grown in California is of common occurrence. This cross-pollination usually occurs between plants adjacent to one another.

Field hybridization between vines within a variety has been shown to cause variation in size and color of seed and vigor and maturity of the vines, as in the case of the Salinas Pinks. Where disease resistance is a character of a variety, this quality may be disturbed or broken down, or in common terms, the variety may "run down". To prevent the running down of varieties by field hybridization, plant selections are made each year to verify the purity. The seed of such pure strains is made available for distribution through the pure seed organization, known as the Calapproved Seed Plan. This process must be continued if the purity of our bean varieties is to be preserved.

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INHERITANCE OF EARLINESS AND LENGTH OF KERNEL IN RICE[1]

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THE primary purpose of this study was to determine if it is possible to isolate from crosses selections that are earlier and later than either parent, and also lines having different kernel lengths than those of the parents.

Crosses between short- and long-grain, short- and medium-grain, and medium- and long-grain varieties, varying in maturity, were made in 1929 at the Biggs Rice Field Station, Biggs, Calif., and the F_1 plants were grown there in 1930. In 1931 seed from the same F_1 plants was sown at the Biggs Rice Field Station, at the Rice Branch Experiment Station, Stuttgart, Ark., and at the Texas Agricultural Substation No. 4, Beaumont, Texas.

These three stations are located in areas having somewhat different environmental conditions, and information on the inheritance of earliness and kernel length from the same crosses, grown under such conditions, should be of interest.

During the growing season from May to September, inclusive, 1931, the average maximum temperature was slightly higher at Biggs, Calif., than at Beaumont, Texas, and Stuttgart, Ark. The average minimum temperature, however, was distinctly lower and the average mean temperature slightly lower at Biggs than at Stuttgart and Beaumont.

At Stuttgart the total precipitation for the 6-month period was 18.40 inches, at Beaumont 17.65 inches, and at Biggs 2.42 inches. The total evaporation was slightly higher at Biggs than at Stuttgart and distinctly higher than at Beaumont. The humidity of the atmosphere at Stuttgart and Beaumont, owing largely to the higher summer precipitation, was naturally higher than that at Biggs.

MATERIAL AND METHODS

The crosses Bozu x Edith, Bozu x Blue Rose, Colusa x Edith, and Colusa x Blue Rose were used in the study of the inheritance of earliness, and the crosses Butte x Edith, Caloro x Honduras, Colusa x Blue Rose, and Edith x Blue Rose were used in the study of the inheritance of kernel length.

Bozu, Colusa, Caloro, and Butte are short-grain varieties. Bozu matures very early, Colusa early, and Caloro and Butte are midseason varieties. Edith and Honduras are long-grain varieties that mature early in the southern States but late in California. Blue Rose is a medium-grain, late-maturing variety.

In the study of earliness the date of first heading of each F_2 plant was recorded.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. The studies herein reported were conducted cooperatively by the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, and the Arkansas, Texas, and California agricultural experiment stations. Received for publication September 25, 1935.

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A plant was recorded as first heading as soon as one or more spikelets had emerged from the leaf sheath. First heading is hereafter referred to as headed.

In the study of the length and breadth (dorsiventral diameter) of seeds or kernels, mature panicles of each F_2 plant were collected and 10 kernels or seeds from the middle of representative panicles of each plant were measured.

EXPERIMENTAL DATA

INHERITANCE OF EARLINESS

The parents and F_1 plants were grown under like conditions at Biggs, Calif., in 1930. First heading of Bozu was on July 14, Colusa on August 13, Edith on September 2, and Blue Rose on September 4. The F_1 plants of Bozu x Edith and Bozu x Blue Rose first headed on August 5, Colusa x Edith on August 27, and Colusa x Blue Rose on August 29. In crosses in which Bozu was used the F_1 plants headed nearer the early than the late parent, whereas in crosses in which Colusa was used the F_1 plants headed nearer the late parent.

F_2 PLANTS

Seed from F_1 plants of the crosses Bozu x Edith, Bozu x Blue Rose, Colusa x Edith, and Colusa x Blue Rose was sown at Stuttgart, Ark., on May 11, at Beaumont, Tex., on April 24, and at Biggs, Calif., on April 7, 1931. The growing season at each station was satisfactory and the plants developed normally. The frequency distribution for date of first heading for the parents and F_2 plants of the crosses are shown in Table 1.

Bozu x Edith and Bozu x Blue Rose.—The segregation of the F_2 plants for earliness in the crosses Bozu x Edith and Bozu x Blue Rose was essentially the same at each station. Most of the F_2 plants in both crosses headed nearer the early than the late parent. At Stuttgart and Beaumont one or more F_2 plants in the cross Bozu x Edith headed later than the late parent, but none was as late as Blue Rose at Biggs. The heading period for the F_2 plants of the cross Bozu x Blue Rose did not extend beyond that of the parents. At each station the first heading of the F_2 plants covered a relatively long period and heading was relatively slow near the end of the heading period. There was a fairly high frequency class in the F_2 plants from both crosses at each station and seemingly minor variations for given dates which were probably due to the effects of variations in climatic conditions as well as to the action of genetic factors.

F_3 PROGENIES

A number of random F_2 families from the crosses Bozu x Edith, Bozu x Blue Rose, Colusa x Edith, and Colusa x Blue Rose were grown in F_3 at Stuttgart, Ark., in 1932. The number of F_2 families grown and results obtained are shown in Table 2. Of the 48 F_2 families from the cross Bozu x Edith four bred true, one being early, one late, and two intermediate. The remaining 44 families were segregating and intermediate in maturity. Of the 40 F_2 families from the cross Bozu x Blue Rose, 1 was as early as Bozu, 6 were early but not so early as Bozu, and the remaining 33 families were segregating and intermediate in maturity.

Station, parents, and cross	Class centers (dates)																					Mean number days seeding to first heading
	June		July							August									September			
	23–26	27–30	1–4	5–8	9–12	13–16	17–20	21–24	25–28	29–1	2–5	6–9	10–13	14–17	18 21	22 25	26–29	30–2	3–6	7–10	11–14	
Stuttgart, Ark.																						
Bozu							4	19	3	1												73 24
Edith																21	11					106 63
F_2								17	30	89	171	90	43	25	25	3	4	4				87 20
Beaumont, Tex																						
Bozu		9	9	3																		69 33
Edith												12	8	3								109 17
F_2			3	21	61	49	49	35	13	12	2	1	1	0	0	0	1					84 38
Biggs, Calif *																						
Bozu	6–23 to 6 27																					72 00
Edith																			9–3 to 9–8			120 00
F_2		6	23	51	78	160	66	52	27	9	3	2	2	2	0	1						94 18
Stuttgart Ark																						
Bozu							4	19	3	1												73 24
Blue Rose																			35	10		118 37
F_2							6	28	36	55	81	42	26	26	30	19	10	6	2			88 28
Beaumont, Tex																						
Bozu		9	9	3																		69 33
Blue Rose																7	8	2				125 94
F_2			37	48	43	27	13	26	26	22	5	13	4	1	0	5						85 07
Biggs, Calif *																						
Bozu	6–23 to 6 27																					72 00
Blue Rose																			9–3 to 9–8			144 00
F_2	2	17	50	43	44	83	32	29	26	27	20	10	20	17	10	19	7					99 76
Stuttgart, Ark																						
Colusa												6	7	7	6							95 50
Edith																21	11					106 63
F_2											12	19	64	55	53	9	31	88	86	36	5	106 75
Beaumont, Tex																						
Colusa								2	9	5	1	1										95 17
Edith												12	8	3								109 17
F_2							3	10	53	33	24	18	20	41	37	44	19	4	1			109 36
Biggs, Calif *																						
Colusa									7 26	to	8 12											106 00
Edith																			9–3 to 9–8			120 00
F_2							2	21	56	49	58	18	16	27	51	47	54	50	43	15	12	125 93
Stuttgart, Ark																						
Colusa												6	7	7	6							95 50
Blue Rose																		35	10			118 37
F_2											2	6	23	27	29	5	12	106	97	31	1	110 88
Beaumont, Tex																						
Colusa								2	9	5	1	1										95 17
Blue Rose																7	8	2				125 94
F_2								2	22	17	10	0	2	19	55	55	9					114 11
Biggs, Calif *																						
Colusa									7–26	to	8 12											106 00
Blue Rose																			9–3 to 9–8			144 00
F_2									4	13	29	17	39	31	25	60	218	146	39			134 15

TABLE 2.—*Segregation of F_3 progenies from the crosses Bozu x Edith, Bozu x Blue Rose, Colusa x Edith, and Colusa x Blue Rose for earliness at Stuttgart, Ark., in 1932*

Cross and number F_2 families grown	Number plants that were			Deviation from		Remarks
	Early	Intermediate	Late	3:1 ratio and probable error	9:7 ratio and probable error	
Bozu x Edith						
1	29					Breeding true
2		46				Breeding true
1			30			Breeding true
44		1,222				Segregating, but not so late as late parent
Bozu x Blue Rose						
1	17					Breeding true
6	128					Breeding true, but not so early as early parent
33		1,123				Segregating, but not so late as late parent
Colusa x Edith						
17	322					Breeding true, but 1 late plant in 5 families and 2 in 1 family
6			87			Breeding true, but 1 early plant in 2 families
8	25		100	6.25±3.27		Segregating as expected
8	52		77		4.44±3.80	Segregating as expected
5	89		42			This unexpected segregation can not be explained
Colusa x Blue Rose						
13	346					Breeding true, but from 1 to 3 late plants in 5 families
9			231			Breeding true, but 1 early plant in 1 family
14	93		283	1.00±5.56		Segregating as expected
1	11		5			Unexpected segregation
Colusa x Blue Rose*						
1	33					Breeding true, but 4 plants slightly later than early parent
5			157			Breeding true
12	107		375	13.50±6.41		Segregating as expected

*Grown at Beaumont, Texas

The frequency distribution of the F_2 plants for date of first heading and the data on the F_3 progenies indicate that Bozu differs in earliness from Edith and Blue Rose by more than two genetic factors, and the earliness of Bozu appears to be partially dominant.

Colusa x Edith.—A number of F_2 plants from the cross Colusa x Edith headed before the earliest Colusa plants and many also headed much later than the latest Edith plants (Table 1). By arbitrarily placing those F_2 plants that headed earlier and over the same period as Colusa in an early group and those that headed later than the latest of the Colusa plants in a late group the ratio at each station was about 9 late to 7 early plants. However, the fact that some plants headed earlier and others much later than either parent indicates that in addition to what appears to be the action of complementary factors, modifying factors also are involved in this case.

F_3 PROGENIES

Of the 44 F_2 families from the cross Colusa x Edith 17 were early (Table 2), 6 were late, 8 segregated in a ratio of 3 late to 1 early plant; 8 segregated in a ratio of 9 late to 7 early plants; and contrary to expectation, 5 families gave 89 early to 42 late plants. The latter results can not be explained satisfactorily. The few late plants in early families and the few early plants in late families may be due, in this and the following cross, to seed that floated in during irrigation, to unfavorable conditions for development, or to natural crossing in F_2. In the cross Colusa x Edith it appears that Colusa carries a factor for lateness which, in the presence of a late factor in Edith, delays the heading of some F_2 plants far beyond that of the Edith parent.

Colusa x Blue Rose.—At Beaumont and Biggs, F_2 plants from the cross Colusa x Blue Rose headed over about the same period as the parents. At Stuttgart, however, two F_2 plants headed earlier and 32 later than either parent. By arbitrarily classifying those F_2 plants that headed after the latest of the Colusa plants as late and all others as early, the ratio of late to early plants at Stuttgart and Beaumont was 3 : 1, but as stated, there were 2 F_2 plants that were earlier and 32 that were later than either parent at Stuttgart, and at Biggs the F_2 plants did not conform well to a simple Mendelian ratio.

Based on the arbitrary classification into two groups, at Stuttgart there were 252 late to 87 early plants; at Beaumont, 140 late to 51 early plants; and at Biggs, 519 late to 102 early plants. The total for Stuttgart and Beaumont was 392 late to 138 early plants and the deviation from a 3 : 1 ratio was 3.00 ± 6.72 plants, whereas at Biggs the deviation was extremely large.

F_3 PROGENIES

Of the 37 F_2 families from the cross Colusa x Blue Rose, grown in Arkansas (Table 2), 3 were early, 9 were late, 14 segregated in a ratio of 3 late to 1 early plant; and, contrary to expectation, 1 family gave 11 early to 5 late plants. Of the 18 F_2 families grown in Texas, 1 was early, 5 were late, and 12 segregated in a ratio of 3 late to 1 early plant.

The breeding behavior in the F_2 and F_3 generations of the cross

Colusa x Blue Rose indicates that the varieties differ in earliness by one main genetic factor and minor modifying factors.

In each of the four crosses used in the study of earliness the standard deviations and coefficients of variability of the F_2 plants were from 2 to 6 times that of the parents and each cross showed essentially the same type of segregation at the three stations. This indicates that in earliness the reaction of F_2 plants to an environment is determined largely by their genetic constitution.

KERNEL LENGTH AND BREADTH

One of the most constant quantitative characters of rice varieties is the length of seeds or kernels. The commercial rices grown in the United States may be classed according to length of kernel as short-grain, medium-grain, long-grain, and long-slender-grain. The F_2 segregation for kernel length in crosses between short- by long-grain varieties was studied in 1931 at Stuttgart Ark., Beaumont, Texas, and Biggs, Calif. At Biggs, F_2 segregation for kernel length also was studied in crosses between short- by medium[a] and long- by medium-grain varieties.

PARENTS AND F_1 PLANTS

The parent and F_1 plants were grown at Biggs in 1930. The average length of Butte and Caloro kernels was 5.0 and 5.2 mm and of Edith and Honduras 7.4 and 7.2 mm, respectively. The average length of F_1 kernels of the crosses Butte x Edith was 5.7 mm and of Caloro x Honduras 6 mm. The F_1 kernels were intermediate in length between the parents but nearer that of the short-grain parents. The average length of the F_1 kernels of the cross Colusa x Blue Rose was 5.7 mm, or the same as the average of the parents, namely, Colusa 5.3 mm and Blue Rose 6.1 mm. The average length of the F_1 kernels of the cross Edith x Blue Rose was 6.1 mm, the same as Blue Rose. Edith kernels averaged 7.4 mm in length. The F_1 seeds of the cross Lady Wright x Caloro averaged 8.11 mm in length and 3.56 mm in breadth. The average length of Caloro and of Lady Wright seeds was 7.12 and 9.26 mm, respectively.

F_2 PLANTS

The frequency distribution for length of kernels of the parents and F_2 plants of the crosses Butte x Edith, Caloro x Honduras, grown at the three stations, and Colusa x Blue Rose and Edith x Blue Rose grown at Biggs, Calif., in 1931 is shown in Table 3.

Butte x Edith and Caloro x Honduras.—The F_2 plants, from the crosses Butte x Edith and Caloro x Honduras, ranged in kernel length from short to long with no evidence of a distinct division into short-grain and long-grain groups, nor into short-, medium-, and long-grain groups. None of the F_2 plants from the cross Butte x Edith produced kernels that were quite so short as those of the shortest Butte plant nor quite so long as those of the longest Edith plant, except for one plant at Biggs. At each station the mean length of kernels of the F_2 plants was intermediate between that of the parents.

None of the F_2 plants from the cross Caloro x Honduras grown at Stuttgart produced kernels that were shorter or longer than those

TABLE 3 —*Frequency distribution for length of kernels of the parents and F_2 plants of the crosses Butte x Edith and Caloro x Honduras grown at Stuttgart, Ark , Beaumont, Texas, and Biggs, Calif , and Colusa x Blue Rose and Edith x Blue Rose grown at Biggs, Calif , in 1931*

Station, parents, and cross	Class centers in millimeters																																		Mean length of kernels
	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	
Stuttgart, Ark																																			
Butte			2	14	15	7	1	1																											5.10
Edith																						2	6	15	13	10	2	1							7.07
F_2							3	10	14	29	43	56	45	54	49	37	18	20	26	12	26	21	11	9	4	2									6.14
Beaumont, Tex																																			
Butte	1	2	3	3	1																														4.91
Edith																							2	2	3	1	1	1							7.10
F_2					2	3	6	14	25	31	31	32	19	43	16	14	16	6	8	6	4	5	6	2	1	1									5.92
Biggs, Calif																																			
Butte		1	0	4																															4.91
Edith																								5											7.03
F_2			1	2	8	9	12	21	35	28	32	34	33	12	14	24	8	11	4	7	2	3	1	1	1										5.80
Stuttgart, Ark																																			
Caloro								5	12	11	3																								5.46
Honduras																											1	1	9	7	12	5	6	1	7.67
F_2								1	1	2	7	17	26	35	46	36	35	29	39	13	22	14	11	18	6	12	8	4	5	0	0	1	1		6.44
Beaumont, Tex																																			
Caloro						1	2	5	2																										5.38
Honduras																										1	2	4	1	0	1	1			7.44
F_2					1	3	6	7	7	10	14	19	9	29	13	17	17	10	13	9	4	12	2	5	1	1	2	2							6.12
Biggs, Calif																																			
Caloro				1	0	0	0	4																											5.31
Honduras																								1	0	4									7.11
F_2					1	0	3	3	12	9	17	19	23	22	19	9	7	7	4	7	7	8	4	2	0	2	1								6.05
Biggs, Calif																																			
Colusa					2	0	3																												5.27
Blue Rose														1	0	4																			6.11
F_2					2	1	4	14	16	26	36	21	24	15	11	2	0	1																	5.72
Edith																								5											7.03
Blue Rose														1	0	4																			6.11
F_2											1	3	3	10	17	22	20	11	18	9	6	6	7	5	7	7	2	4	3						6.48

of the shortest and longest parent plants. At Beaumont, only one plant produced shorter kernels than those of the shortest Caloro plant and at Biggs one plant produced longer kernels than those of the longest Honduras plant. At each station the mean kernel length of the F_2 plants was intermediate between that of the parents but slightly nearer that of the short-grain Caloro parent.

Kernel length, as indicated by the segregation of the F_2 plants of the crosses Butte x Edith and Caloro x Honduras, appears to be due to the action of multiple factors.

In general, the kernels of the parents and F_2 plants were slightly longer at Stuttgart than they were at Beaumont, and slightly longer at Beaumont than they were at Biggs. The nature of the distribution of the F_2 plants for kernel length appears, however, to be essentially the same at the three stations, regardless of the differences in environmental conditions.

At Stuttgart the breadth of the kernels of the parents and F_2 plants of the crosses Butte x Edith and Caloro x Honduras was measured. The kernels of F_2 plants from the cross Butte x Edith ranged from 2.5 to 3.1 mm in breadth. Many exceeded those of Butte in breadth while others had less breadth than those of Edith. The mean breadth of the kernels of F_2 plants was, however, greater than that of Butte.

The breadth of F_2 kernels from the cross Caloro x Honduras ranged from 2.5 to 3.2 mm. Many F_2 plants produced kernels that had a larger breadth than the largest Caloro kernels and a few had less breadth than the smallest Honduras kernels. In other words, there was transgressive segregation of the F_2 plants for breadth of kernel, but the mean kernel breadth of the F_2 plants was intermediate between that of the parents but slightly nearer that of the Caloro parent which has kernels of larger breadth than those of Honduras.

Segregation of F_2 plants in the crosses Butte x Edith and Caloro x Honduras for breadth of kernel indicates that this character is probably controlled by multiple factors.

Colusa x Blue Rose and Edith x Blue Rose.—The kernels of F_2 plants of the cross Colusa x Blue Rose grown at Biggs, Calif., ranged in length from slightly shorter than those of Colusa to slightly longer than those of Blue Rose (Table 3). Most of the F_2 plants, however, produced kernels that were intermediate in length between those of the parents but slightly nearer that of Blue Rose. There was no indication of a distinct separation into groups having different kernel lengths.

The kernels of F_2 plants of the cross Edith x Blue Rose grown at Biggs ranged in length from shorter than those of Blue Rose to longer than those of Edith, but most of the F_2 plants were intermediate in kernel length between those of the parents but slightly nearer that of Blue Rose. There was no distinct segregation into medium-grain and long-grain groups nor into medium-grain, intermediate-grain, and long-grain groups. The fact that a number of F_2 plants produced kernels that were shorter than those of Blue Rose and other plants produced kernels that were longer than those of Edith indicates that kernel length in this cross was due to the action of multiple factors,

although the genetic factors responsible for the medium-grain type appear to be partly dominant.

Kernel length in the crosses Colusa (short) and Edith (long) x Blue Rose (medium) appears to be controlled, as in the other crosses discussed, by multiple factors.

Lady Wright x Caloro.—The cross Lady Wright (long) x Caloro (short) was made at Biggs, Calif., in 1924. Caloro seeds averaged 7.12, Lady Wright 9.26, and those of F_1 plants 8.11 mm in length. The average length of the F_1 seeds was practically the same as that of the average of the parents. Seed of 200 F_2 plants ranged from 7.1 to 9.5 mm in length or over practically the entire range of the parents. Some F_2 plants produced seeds that were shorter and longer, respectively, than the average of those of the parent varieties. The average length of the seeds of F_2 plants was 8.08 mm, being somewhat nearer the average length of the seeds of Caloro than that of Lady Wright. There was no sharp division of the F_2 plants into short-, medium-, and long-grain groups as would be expected if seed length were due to one or two genetic factors. On the contrary, the data indicate that seed length in this cross is controlled by multiple factors.

In subsequent generations an attempt was made to establish true breeding lines having kernels shorter than those of Caloro, intermediate between those of Caloro and Lady Wright, and longer than those of Lady Wright. At the end of the crop year 1932 several selections appeared to be breeding true for kernel length. The range in kernel length of the true-breeding strains and the parents is shown in Table 4. The kernels of selection 48–1 undoubtedly are shorter and those of selections 48–6 and 130–2 are probably shorter than those of Caloro. Two selections have kernels of the same length as those of Caloro, that is, 5.2 mm. Several selections ranging in kernel length from 5.3 to 6.8 are intermediate between the parents. Three selections appear to have kernels slightly longer than those of Lady Wright, but the increase in length is so small that they probably are not significant.

The fact that true-breeding lines, varying in kernel length from 4.8 mm to 7.1 mm, have been isolated from this cross is good evidence that kernel length is due in this case to the action of multiple factors.

Since the progeny from crosses herein used in the study of kernel length have reacted in essentially the same way at the three stations, it seems fair to conclude that the parents used differ for length of kernels by more than two genetic factors.

This conclusion is supported by the fact that true-breeding lines have been isolated from the cross Lady Wright x Caloro and reciprocal that have kernels of various gradations in length between those of the parents. In selection work in the third and fourth generations of the other crosses studied, lines also have been observed with gradations in kernel length between those of the parents. In dealing with quantitative characters, such as length and breadth of kernels, it is to be expected that several genetic factors are likely to be involved.

TABLE 4.—*Length of kernels of apparently true-breeding lines isolated from the cross Lady Wright x Caloro and reciprocal grown at Biggs, Calif., in 1932.*

Variety or selection	Length of kernel in millimeters									
	4.8	5.0	5.2	5.3	5.4	5.8	6.2	6.8	7.0	7.1
48–1	+									
48–6		+								
130–2		+								
Caloro (parent)			+							
48–4			+							
48–10			+							
48–3				+						
20–1					+					
241B5–30						+				
241Bp 131–2						+				
241B21–3–1							+			
124–1								+		
Lady Wright (parent)									+	
1–1									+	
1–2									+	
61–3									+	
55–2										+
61–2										+
124–3										+

DISCUSSION

The nature of the F_2 segregation for earliness depends upon the varieties crossed. In the crosses Bozu x Edith and Bozu x Blue Rose the segregation for earliness herein reported indicates that this character is controlled by multiple factors and that the factors for earliness in Bozu are partially dominant. Others (3, 4, 5, 6, 9)[3] have reported that segregation for earliness in F_2 was apparently controlled by multiple factors.

In the crosses Colusa x Blue Rose and Colusa x Edith the F_2 plants, when arbitrarily divided into late and early groups on the assumption that all plants as early as the latest Colusa plant were early and all others late, gave about 3 late to 1 early and 9 late to 7 early plants, respectively. However, there were at Stuttgart, Ark., F_2 plants in the cross Colusa x Blue Rose that were earlier and later than either parent, and at Biggs, Calif., where climatic conditions are unfavorable for the development of late plants, the number of late plants was far in excess of those expected on a 3 late to 1 early basis. These facts indicate that earliness in this cross was probably determined by one main and also modifying factors.

At each station some F_2 plants from the cross Colusa x Edith headed earlier and others later than either parent. This transgressive segregation indicates that probably a number of factors are involved. However, on the basis of the arbitrary grouping mentioned above, the F_2 segregation agrees in general with a 9 late to 7 early ratio. This agreement does not mean that only complementary factors are involved in the segregation for this character but that the segregation

[3]Figures in parenthesis refer to "Literature Cited", p. 920.

does appear to be dominated by complementary factors. A segregation in F_2 of 3 late to 1 early plant in rice crosses has been reported by other workers (1, 2, 6, 7).

The segregation of F_2 plants for length and breadth of kernels in crosses herein reported indicates that the varieties used differ by multiple factors. In the cross Lady Wright x Caloro and reciprocal, true-breeding lines varying in kernel length from shorter than the short parent to as long as the long parent have been isolated. This indicates that kernel length in this cross was controlled by multiple factors, and indications are that this also is true for the other crosses studied. Ramiah (10) reports that grain length and width are due to the action of multiple factors. On the contrary, Parnell (8) and van der Stok (11, 12) obtained F_2 ratios of 1 short to 2 intermediate to 1 long or long-slender grain plant.

SUMMARY

The segregation in F_2 for date of first heading in the crosses Bozu x Edith and Bozu x Blue Rose appeared to be controlled by multiple genetic factors; in the cross Colusa x Edith mainly by complementary genetic factors indicating a 9 late to 7 early ratio; and in the cross Colusa x Blue Rose largely by one main genetic factor giving about 3 late to 1 early plant.

In the F_2 populations of the crosses Butte x Edith, Caloro x Honduras (short- x long-grain), Lady Wright x Caloro (long- x short-grain), Colusa x Blue Rose (short- x medium-grain), and Edith x Blue Rose (long- x medium-grain) the length of kernel and the breadth of kernel in two crosses appeared to be controlled by multiple genetic factors.

The F_2 segregation at the three stations for date of first heading and kernel length was essentially the same regardless of the differences in climatic conditions. This indicates that under the conditions at the three stations where this work was done, the nature of the segregation of hybrid material is determined primarily by the genotypic constitution of the varieties used rather than by the climatic conditions under which the material is grown.

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THE MAGNESIUM CONTENT OF GRASSES AND LEGUMES AND THE RATIOS BETWEEN THIS ELEMENT AND THE TOTAL CALCIUM, PHOSPHORUS, AND NITROGEN IN THESE PLANTS[1]

HARLEY A. DANIEL[2]

INFORMATION concerning the magnesium content of plants is very limited compared with the large amount of data that has been published on the chemical composition of various crops for many other common elements.

Latshaw and Miller (3)[3] studied the composition of five corn plants and found that the average magnesium content of the stems, grain, cobs, and roots was 0.179%. Miller (4) showed that cowpeas, soybeans, and andropogons contained 0.50, 0.70, and 0.19% of magnesium, respectively.

In a report on the influence of magnesium deficiency on phosphorus absorption of soybeans, Willis, Piland, and Gay (5) found a negative correlation of —.39 existing between CaO:MgO, and a positive correlation of .19 for $MgO:P_2O_5$ in these plants.

EXPERIMENTAL PROCEDURE

Composite samples of mature native grass were collected during 1930 to 1934, inclusive, from typical areas of native pasture land and from hay meadows grown on virgin soils in 35 counties of Oklahoma. The mature legumes were collected on the experiment station farms at Stillwater and Perkins, Oklahoma, at the time the plants were cut for hay.

The legume tops and roots were also collected on these farms each week when possible from April 1 to May 20, 1933. The roots of these plants were carefully removed from the soil by digging at the same time the tops were collected and washed several times with water to remove the soil.

The samples were dried at 105°C and were analyzed for total calcium, phosphorus, and nitrogen by official methods recommended by the Association of Official Agricultural Chemists. The filtrate was saved from the calcium determinations in each case and analyzed for total magnesium by Hibbard's (2) titration method in which the precipitate of magnesium ammonium phosphate was dissolved in 1/10 N standard acid and back titrated with a standard sodium hydroxide solution until neutral to methyl red.

RESULTS

MAGNESIUM CONTENT OF GRASSES AND LEGUMES

The magnesium content of 162 samples of mature grasses and legumes were studied and the data recorded in Table 1. According to these data, the average magnesium content of 19 different species of

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[2]Assistant Agronomist. The author wishes to express his appreciation to Randall Jones, student assistant, for the magnesium analyses, and to Dr. H. J. Harper, Professor of Soils, for collecting the samples analyzed in Table 2.

[3]Figures in parenthesis refer to "Literature Cited", p. 927.

TABLE 1.—*The total magnesium content of mature grasses and legumes and the ratios between this element and the total calcium, phosphorus, and nitrogen content in these plants.*

Sample No.	Common name	Botanical name	No. of samples analyzed	Mg %	Ratios		
					Ca/Mg	P/Mg	N/Mg
		Grasses					
1	Little blue stem	*Andropogon scoparius*	30	0.138	1.84	0.46	3.95
2	Big blue stem	*Andropogon furcatus*	10	0.170	1.38	0.43	3.26
3	Big and little blue stem	*Andropogon furcatus* and *scoparius*	19	0.169	1.79	0.44	3.95
4	Short grass	*Bouteloua* and *Buchloe*	21	0.135	2.59	0.78	6.99
5	Grama grass	*Bouteloua gracilis*	8	0.145	2.16	0.69	6.43
6	Buffalo grass	*Bouchloe dactyloides*	9	0.148	1.92	0.73	5.76
7	Indian grass	*Sorghastrum nutans*	1	0.156	1.48	0.62	4.13
8	Triple-awn grass	*Aristida oligantha*	2	0.171	1.14	0.71	6.39
9	Diffused crab grass	*Leptoloma cognatum*	2	0.238	1.90	0.53	3.98
10	Broom sedge	*Andropogon virginicus*	3	0.102	2.35	0.82	5.98
11	Silver beard grass	*Andropogon torreanus*	2	0.202	1.62	0.56	3.55
12	Switch grass	*Panicum virgatum*	1	0.169	1.38	0.69	2.98
13	Love grass	*Eragrostis curtipedicellata*	1	0.059	5.46	2.42	22.06
14	——	*Sporobulus asper*	1	0.169	1.17	0.58	3.37
15	Salt grass	*Distichlis spicata*	1	0.184	1.73	0.70	5.17
16	Giant reed grass	*Calamovilfa longifolia*	1	0.130	1.10	0.96	3.92
17	Purple top	*Triodia flava*	1	0.189	1.37	0.65	6.08
18	Redtop	*Agrostis alba*	1	0.300	1.23	0.48	2.25
19	Sorghum	*Andropogon sorghum*	3	0.316	1.12	0.19	2.09
	Av. all grasses		117	0.156	1.86	0.56	4.68
		Legumes					
20	Cowpeas	*Vigna sinensis*	8	0.380	3.96	0.56	6.02
21	Velvet beans	*Stizolobium deeringianum*	4	0.329	4.19	0.66	6.59
22	Soybeans	*Soja max*	6	0.457	2.09	0.47	4.53
23	Peanut vines	*Arachis hypogaea*	6	1.024	2.00	0.09	—
24	Sweet clover	*Melilotus alba*	5	0.348	3.20	0.40	—
25	Alfalfa	*Medicago sativa*	16	0.345	5.34	0.53	7.69
	Av. all legumes		45	0.379	4.14	0.46	6.33*

*Average of 34 nitrogen samples.

TABLE 2.—*The magnesium content of legume tops and roots and the ratios between this element and the total calcium, phosphorus, and nitrogen in the plants at different stages of growth in 1933.*

Sample No.	Name of plant	Date collected	No. of samples analyzed	Tops Mg %	Tops Ratios Ca/Mg	Tops Ratios P/Mg	Tops Ratios N/Mg	Roots Mg %	Roots Ratios Ca/Mg	Roots Ratios P/Mg	Roots Ratios N/Mg
1	Austrian winter field pea*	Apr. 1	3	0.439	2.46	0.69	9.59	0.327	2.59	0.57	7.75
2	Hairy vetch†	Apr. 1	2	0.272	5.00	0.64	12.94	0.291	2.76	0.36	8.02
3	Sweet clover‡	Apr. 1	1	0.471	1.86	0.33	6.11	0.444	1.97	0.40	6.19
Av.		Apr. 1	6	0.389	2.93	0.61	9.66	0.334	2.50	0.47	7.49
4	Austrian winter field pea	Apr. 8	3	0.431	2.88	0.67	9.86	0.273	3.51	0.54	8.73
5	Hairy vetch	Apr. 8	2	0.253	4.90	0.86	12.89	0.224	4.04	0.65	10.04
6	Sweet clover	Apr. 8	1	0.404	2.50	0.49	7.00	0.374	2.39	0.53	7.25
Av.		Apr. 8	6	0.367	3.37	0.68	10.00	0.273	3.40	0.57	8.65
7	Austrian winter field pea	Apr. 15	3	0.385	3.44	0.79	11.28	0.230	3.64	0.71	10.90
8	Hairy vetch	Apr. 15	2	0.260	4.65	0.91	14.62	0.213	3.58	0.57	12.05
9	Sweet clover	Apr. 15	1	0.460	4.07	0.57	8.40	0.263	1.62	0.42	7.30
Av.		Apr. 15	6	0.355	3.60	0.77	11.52	0.230	3.23	0.61	10.58
10	Austrian winter field pea	Apr. 29	2	0.348	3.49	1.35	9.95	0.180	5.82	0.86	13.65
11	Hairy vetch	Apr. 29	2	0.255	5.15	0.97	10.65	0.199	4.24	0.56	11.55
12	Sweet clover	Apr. 29	1	0.381	4.07	0.42	6.75	0.359	1.25	0.24	7.02
Av		Apr. 29	5	0.317	4.15	0.86	9.42	0.223	3.78	0.56	10.80

13	Austrian winter field pea	May 5	3	0.343	3.11	0.68	9.79	0.223	4.07	0.43	10.32
14	Hairy vetch	May 5	2	0.265	3.07	0.71	11.30	0.220	4.47	0.41	9.45
15	Sweet clover	May 5	1	0.325	4.28	0.71	8.72	0.303	2.60	0.52	5.80
Av.		May 5	6	0.315	3.30	0.69	10.00	0.235	3.89	0.45	9.10
16	Austrian winter field pea	May 13	2	0.280	3.30	0.70	10.04	0.190	5.45	0.77	12.50
17	Hairy vetch	May 13	1	0.224	2.20	0.72	10.65	0.247	3.32	0.47	8.42
18	Sweet clover	May 13	6	0.322	3.28	0.51	7.99	0.326	1.73	0.35	5.92
Av.		May 13	9	0.302	3.18	0.57	8.75	2.287	2.43	0.42	7.28
19	Austrian winter field pea	May 20	1	0.269	3.58	0.78	10.92	0.169	5.45	0.72	13.32
20	Hairy vetch	May 20	1	0.224	4.20	0.93	12.40	0.179	3.96	0.52	10.00
Av.		May 20	2	0.246	3.88	0.85	11.62	0.173	4.70	0.62	11.72
	Av. all samples		40	0.334	3.38	0.69	9.95	0.262	3.12	0.50	8.68

**Pisum arvense.*
†*Vicia villosa.*
‡*Melilotus alba.*

grasses was 0.156%. These plants varied in percentages of this element from 0.059 to 0.316. The percentage of magnesium was higher in redtop grass and sorghum than in any of the native grasses. Love grass contained the lowest percentage of this element and sorghum the highest. These data show that the six different species of mature legumes averaged 0.379% magnesium. The velvet beans contained the lowest amount (0.329%) of this element and the peanut vines the highest (1.024%). Peanut vines were found to contain 2.24 times more magnesium than soybeans, the next highest plant. The legumes contained as an average 2.43 times as much magnesium as the grasses.

The data in Table 2 show the magnesium content of legume tops and roots at different stages of growth in 1933. Although there was a considerable variation in the individual plants, the average of the weekly samples showed that the percentage of magnesium decreased as the plant matured. With exception of the samples that were collected May 5 and May 13, the magnesium content of the roots of these plants also decreased as the plants matured. The percentage of this element in the tops varied from 0.246 to 0.389 and that in the roots from 0.173 to 0.334.

RATIOS BETWEEN PERCENTAGES OF MAGNESIUM AND TOTAL CALCIUM, PHOSPHORUS, AND NITROGEN IN PLANTS

The ratios between the percentages of magnesium and the total calcium, phosphorus, and nitrogen in the mature grasses and legumes are given in Table 1. The grasses averaged 1.86 times as much calcium, and 4.68 times as much nitrogen as magnesium, while they contained 1.79 times as much magnesium as phosphorus. The mature legumes were found to have a higher ratio of calcium and nitrogen to magnesium than the grasses. These plants averaged 4.14 times as much calcium and 6.33 times as much nitrogen as magnesium, and 3.72 times as much magnesium as phosphorus.

Due to the very low phosphorus content of peanut vines (1) and the very high magnesium content, these plants contain 11.1 times as much magnesium as phosphorus. All of the 19 species of grasses and the 6 different mature legumes studied contained more magnesium than phosphorus except love grass, and this plant contained 4.42 times as much phosphorus as magnesium. However, only one sample of this grass was analyzed. It is quite evident that the plants contained more calcium and nitrogen than magnesium and more magnesium than phosphorus, but very little relation seemed to exist between the content of magnesium and that of the other elements studied.

The rations between the magnesium and the total calcium, phosphorus, and nitrogen in the legume tops and roots are given in Table 2. The averages of these ratios were slightly higher in the tops than in the roots. The calcium-magnesium ratios in the tops varied from 1.86 to 5.15, the phosphorus-magnesium ratios from 0.33 to 1.35, and the nitrogen-magnesium ratios from 6.11 to 12.94. The ratios of these elements in the roots were found to vary similarly to those in the tops. The calcium-nitrogen ratios in the roots of the legume

plants varied from 1.25 to 5.82, the phosphorus-magnesium ratios from 0.36 to 0.86, and the nitrogen-magnesium ratios from 5.80 to 13.65.

A careful study of the data given in Table 2 shows that there was very little relation between the chemical composition of the tops of plants and the same elements in the roots. The data seemed to indicate that the percentages of magnesium and nitrogen in the tops were more closely related to those in the roots than was the case with either calcium or phosphorus.

SUMMARY

The total magnesium content and the ratios between the total calcium, phosphorus, and nitrogen were studied in 162 mature plants and the tops and roots of 40 samples of legumes collected at different stages of growth.

The average magnesium content of the 19 species of mature grass was 0.156% and that of the 45 mature legumes 0.379%.

The grass varied in percentage of this element from 0.059 to 0.316 and the legumes from 0.329 to 1.024. Legumes were found to contain 2.43 times as much magnesium as the grasses. The data obtained showed that the magnesium content of legumes decreased as the plants matured.

The calcium-magnesium ratios varied in the mature grasses and legumes from 1.10 to 5.46, the phosphorus-magnesium ratios from 0.09 to 2.42, and the nitrogen-magnesium ratios from 2.09 to 22.06. The data recorded showed that the average of these ratios was slightly higher in the legume tops collected at different stages of growth than in the roots.

Very little relation was found to exist between the chemical composition of the tops of the plants and that of the roots.

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THE RELATION BETWEEN BUSHEL WEIGHT AND MATURITY IN CORN[1]

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MATURITY is extremely important in corn grown under short-season conditions, such as those found in northern Colorado. It would be an advantage to the farmer to be able to detect immaturity in the seed he purchases through some simple test. Work conducted at the Colorado Experiment Station over a 3-year period indicates that the bushel-weight test may be used as an index of maturity in corn. This seems to be the case even though the bushel-weight determinations may be made several months after the corn is harvested.

LITERATURE REVIEW

There has been very little work published on the relation of bushel weight to maturity in corn, although bushel weight is regarded as a quality factor in the federal grain standards (1).[3] These standards require the following minimum bushel weights for grades 1 to 5, inclusive: 54, 53, 51, 48, and 44 pounds, respectively, per Winchester bushel. Lyon and Montgomery (2) early pointed out that deep-kerneled corn varieties grown under short-season conditions would produce comparatively deep but light-weight kernels. The bushel-weight requirements were made to discourage the sale of light-weight corn.

Robertson, *et al.* (3), reported that weight per measured bushel gave an indication of maturity in corn. They found that corn planted after May 10 gave progressively lower bushel weights after harvest as the season advanced. The corn from the later plantings was immature at the time of harvest. Their average bushel weights over a 4-year period were as follows for the April 20, May 1, May 10, May 20, May 30, and June 10 dates of planting: 57.8, 56.8, 55.2, 54.0, 51.6, and 45.5 pounds, respectively. Higher grain quality, as indicated by the bushel weight, characterized the corn planted at the earlier dates.

MATERIALS AND METHODS

Two field varieties of yellow dent corn, a Golden Glow selection and Pride of the North, were used in the test which was conducted over a 3-year period, 1931 to 1933. The first variety was grown all 3 years, while the second was used only in 1931 and 1933. Both varieties were planted each year between May 1 and 10, the optimum planting time for full-season corn at the Colorado Experiment Station. Golden Glow matured in the field each year on or about September 15, while Pride of the North matured a few days earlier.

Individual ears were harvested at five different dates, 10 days apart. These dates were August 22, September 1, September 11, September 21, and October 1. Sixty ears were harvested consecutively from a random place in the row for each

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[3]Figures in parenthesis refer to "Literature Cited," p 933.

variety on each date.[4] The field weights of the individual ears were taken, the ears tagged, and spread out on a floor where they remained until air-dry.

After being thoroughly dried, the ears were weighed again. Each ear was shelled and the bushel weight taken with a small grain kettle (Fig. 1). These determinations were usually made about 6 months after the harvest was completed. Three bushel-weight determinations were made on each ear and the average computed. It was necessary to discard some ears because they provided too little corn to fill the kettle, especially those harvested August 22. After the individual-ear bushel weights were taken, 100 kernels were counted for each ear, weighed, and then dried in a vacuum oven for 24 hours. The corn that remained was bulked for each variety at each date of harvest. The bushel weight was then determined on the composite sample with the standard bushel weight tester as prescribed in the Handbook of Official Grain Standards (4). This served as a check on the accuracy of the averages of the individual-ear determinations.

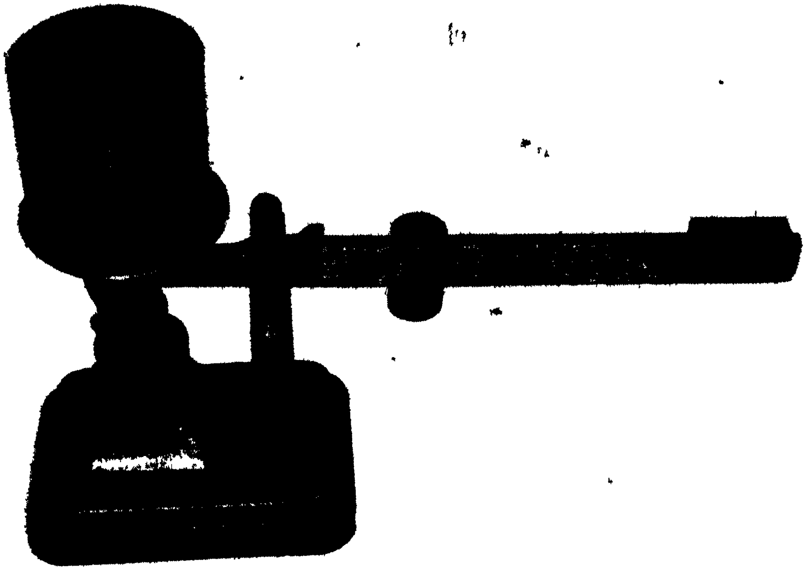

FIG. 1.— Small grain kettle used in making individual ear bushel-weight determinations. The drop from the bottom of the hopper to the top of the kettle was approximately 4 inches.

The mean bushel weight was determined for each variety for each date of harvest. Also, the percentage of moisture of ear corn on an air-dry basis and the mean weights per 100 kernels were computed. Standard errors were calculated in all cases. The correlation coefficient (5) was obtained for (a) bushel weight and percentage moisture of ear corn on an air-dry basis, (b) bushel weight and air-dry weight per 100 kernels, and (c) bushel weight and oven-dry weight per 100 kernels. The significance of the correlation coefficient was determined from Table V (A) given by Fisher (6).

[4]Only 40 ears were harvested in 1931.

EXPERIMENTAL RESULTS

The data are presented only for the Golden Glow variety which was grown over a 3-year period. The results for Pride of the North, which was grown for 2 years, were similar to those obtained for Golden Glow and substantiated the conclusions drawn from the latter.

BUSHEL WEIGHT DETERMINATIONS

It will be seen from Table 1 that the individual-ear bushel weights progressively increased as the time of harvest was delayed, especially up to the point of field maturity which was reached about September 15. The bushel weight remained fairly constant after the corn was mature. The data show it to weigh over 54 pounds, the minimum requirement for U. S. No. 1 corn in the federal grain standards (1). In fact, the mature corn weighed over 56 pounds, the U. S. standard bushel weight for shelled corn. The Golden Glow strain harvested on September 1, which field observations showed to be in the soft dough stage at the time, averaged U. S. No. 2 corn for which the minimum weight is 53 pounds. The corn harvested August 22 obviously was immature at the time as shown by the fact that many ears were in the milk stage. The average bushel weight was below 50 pounds, placing this corn down to U. S. No. 4 for which the minimum requirement is 48 pounds. This corn proved to be chaffy when air-dry. The composite bushel weights, made from a mixture of corn from all ears, agree closely with the means determined from the individual ears.

TABLE 1.—*Bushel weights of Golden Glow corn harvested at 10-day intervals, 1931–33, inclusive*

Date harvested	Mean weight per measured bushel, lbs.			
	1931	1932	1933	Mean*
	Individual Ear Determinations			
Aug. 22.	49.8±0.932	———†	47.0±0.852	48.40±0.631‡
Sept. 1..	54.4±0.560	53.7±0.546	52.6±0.405	53.57±0.296
Sept. 11.	58.0±0.350	56.2±0.476	57.1±0.405	57.10±0.239
Sept. 21.	59.4±0.252	57.6±0.276	58.1±0.300	58.37±0.160
Oct. 1...	59.3±0.325	58.4±0.281	59.4±0.224	59.03±0.162
	Standard Determination on Composite			
Aug. 22.............	49.1	45.4§	46.9	47.13
Sept. 1..............	54.5	54.2	53.5	54.07
Sept. 11.............	58.0	56.2	57.1	57.10
Sept. 21.............	58.8	57.9	58.5	58.40
Oct. 1...............	59.4	58.5	59.6	59.17

*Average of an average.
†Insufficient corn to make individual-ear bushel weight determinations with the size of grain kettle used.
‡Two-year average.
§Based on composite of all harvested ears.

WEIGHTS PER 100 KERNELS

The air-dry weights per 100 kernels increased for successive harvests up to the point of field maturity, i.e., September 15; thereafter, the air-dry weights remained practically constant. The data appear

in Table 2. There was no significant gain in weights per 100 kernels between the September 21 and October 1 dates of harvest. The differences in bushel weights between these two dates also are slight. The oven-dry weights per 100 kernels show the same general trends. The whole kernels were dried for 24 hours in the vacuum oven in 1931 and in 1932, but it was later found that they were not reduced to a moisture-free basis in this length of time as determined by the Brown-Duval moisture tester (4). In 1933, a ground sample from each ear was dried in the vacuum oven for 24 hours.

TABLE 2.—*Weights per 100 kernels of Golden Glow corn harvested at 10-day intervals, 1931–33, inclusive.*

Date harvested	Mean weights per 100 kernels, grams			
	1931	1932	1933	Mean*
	Air-Dry Weight			
Aug. 22	16.84±0.611	14.03† ——	14.80±0.645	15.22 ——
Sept. 1	22.74±0.539	21.69±0.640	21.24±0.516	21.89±0.328
Sept. 11	28.95±0.530	25.41±0.640	27.87±0.531	27.41±0.329
Sept. 21	30.45±0.565	29.79±0.580	30.07±0.577	30.10±0.331
Oct. 1	30.45±0.637	30.34±0.540	32.07±0.589	30.95±0.341
	Oven-Dry Weight‡			
Aug. 22	15.78±0.584	——	13.15±0.697	14.47±0.455§
Sept. 1	21.14±0.504	20.13±0.620	19.82±0.480	20.36±0.311
Sept. 11	26.80±0.496	23.53±0.600	25.75±0.498	25.36±0.306
Sept. 21	28.56±0.616	27.85±0.520	27.79±0.531	28.07±0.322
Oct. 1	28.34±0.596	28.06±0.500	——	——

*Average of an average.
†Average of three determinations from composite shelled corn for this date.
‡Oven-dry weights computed from the moisture determinations made on 5-gram samples of ground corn from each ear on which an individual-ear bushel-weight determination was made.
§Two-year average.

CORRELATIONS WITH BUSHEL WEIGHT

The correlation coefficients between bushel weight and percentage of moisture in ear corn on an air-dry basis (Table 3) indicate a high significant negative correlation for immature corn. Previous data showed the corn to be mature about September 15. No significant correlations were obtained for corn harvested after maturity had been reached.

The correlation coefficients between bushel weight and air-dry weights per 100 kernels indicate a tendency for the correlation to be positive and significant in 1931 and 1932 for the August 22 and September 1 dates of harvest, but not significant in 1933. Thereafter, the results are erratic, with a tendency toward a low positive relationship which may be ascribable to chance in most instances.

When bushel weight was correlated with oven-dry weight per 100 kernels, the correlation coefficients were observed to be similar in behavior to those obtained for air-dry weights per 100 kernels.

TABLE 3.—*Correlations between bushel weight and other characters in Golden Glow corn, 1931–33, inclusive.*

Date harvested	No. ears	Bushel weight correlated with* % moisture ear corn air-dry basis	Air-dry weight per 100 kernels	Oven-dry weight per 100 kernels	Expected r-value for P=0.05†
		1931			
Aug. 22....	17	—0.953	+0.742	+0.755	0.4821
Sept. 1....	38	—0.934	+0.497	+0.508	0.3206
Sept. 11...	38	—0.381	—0.048	—0.062	0.3206
Sept. 21...	40	—0.059	—0.045	—0.037	0.3125
Oct. 2.....	38	+0.321	+0.413	+0.418	0.3206
		1932			
Aug. 22....					
Sept. 1....	33	—0.855	+0.649	+0.625	0.3444
Sept. 11...	31	—0.555	—0.011	—0.097	0.3557
Sept. 21...	54	—0.262	+0.310	+0.261	0.2686
Oct. 1.....	54	+0.129	+0.380	+0.181	0.2686
		1933			
Aug. 22....	16	—0.894	+0.325	+0.226	0.4973
Sept. 1....	46	—0.799	+0.214	+0.219	0.2909
Sept. 11...	51	—0.793	+0.332	+0.425	0.2761
Sept. 21...	54	———	+0.243	+0.255	0.2686
Oct. 1.....	52	———	+0.102	———	0.2732

*Obtained r-value. "r" equals correlation coefficient.
†From Table V (A) by Fisher (6). The r-value is obtained by interpolation where the degrees of freedom are not given exactly. The correlation is not considered significant when the probability that a correlation could exist with unrelated data is greater than P = 0.05.

CONCLUSIONS

The data presented indicate that bushel weight may be taken as an index of maturity. The bushel weights of Golden Glow, a yellow dent variety, progressively increased as it became more mature at the time of harvest. When harvested after maturity in the field, September 15, there was little change in bushel weight.

Mature Golden Glow corn had a bushel weight well over 54 pounds, the minimum requirement for U. S. No. 1 corn. The immature corn harvested August 22 would grade U. S. No. 4 on bushel weight.

The method of making individual-ear bushel weight determinations used in this test agreed with results obtained with the standard bushel weight tester.

The air-dry and oven-dry weights per 100 kernels increased markedly with successive dates of harvest until maturity was reached after which they remained practically constant.

The correlation coefficients between bushel weights and percentage moisture of ear corn on an air-dry basis indicate high significant negative correlations when the corn was harvested at immature stages. The correlation coefficients were low and lacked statistical significance for corn harvested after it had reached maturity in the field.

The correlation coefficients between bushel weights and air-dry weights per 100 kernels were somewhat erratic, although generally low and positive. The coefficients for the August 22 and September 1 dates of harvest were significant in 1931 and 1932, but not in 1933. The same general trends were observed for the correlation coefficients between bushel weights and oven-dry weights per 100 kernels.

Farmers in Colorado should suspect the maturity of Golden Glow corn when harvested if the bushel weight falls below 54 pounds, the minimum requirement for U. S. No. 1 corn under the federal grain standards.

The same general results were obtained over a 2-year period with Pride of the North, an earlier maturing variety.

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DECOMPOSITION OF ORGANIC MATTER IN NORFOLK SAND: THE EFFECT UPON SOIL AND DRAINAGE WATER[1]

CHARLES E. BELL[2]

IN a previous publication (3)[3], studies were reported relative to the rate of decomposition of various organic materials when added to Norfolk sand. The rate of decomposition was measured by the amount of carbon dioxide evolved and quantity of nitrates found in the soil.

The present article deals with the effect of these organic materials on the soil as indicated by changes in reaction, loss through leaching, and exchangeable bases. The same soils used in previous experiments were used for obtaining data for this report. The dried organic materials were added to the soil at the rate of 1% by weight. All organic salts were added on a basis which would supply plant food equivalent to that contained in 100 pounds of a 4-8-4 commercial fertilizer per acre of 67 citrus trees, or an average of 1.5 pounds per tree. The data in this investigation, unless otherwise stated, were obtained after the soils had stood for a period of 1 year. For a complete description of the experiment the reader is referred to an earlier paper (3). The soil was treated as shown in Table 1.

The containers used in the experiment were ordinary 4-gallon, glazed, earthenware pots with a ¾-inch hole in the side near the bottom which facilitated drainage.

The materials were weighed out, thoroughly incorporated in the soil, and placed in the pots. There was a total of 72 pots, each treatment being made in quadruplicate. Two of these series (36 pots) were kept fallow while the other two (36 pots) were set with two seedlings of *Citrus* (*Citrus aurantium* L.). One fallow pot of each treatment (18 pots) was placed in the greenhouse under somewhat controlled temperature and moisture conditions, while the other fallow pot of each treatment (18 pots) was placed outside the greenhouse under ordinary atmospheric or field conditions. One pot of each treatment set to citrus seedlings was likewise placed in the greenhouse and one outside. By following this method it was possible to have two series of the soil treatments (as outlined above) in the greenhouse and two outside, one each of these series of 18 pots fallow and one series set with citrus seedlings. After all the seedlings were set, water was added to the pots in sufficient quantity to bring the moisture content up to 50% of the water-holding capacity of the virgin soil. This percentage of water (added as tap water) was maintained throughout the experiment in all pots kept in the greenhouse.

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[3]Figures in parenthesis refer to "Literature Cited", p. 945.

TABLE 1.—*Quantities (grams) of material added to 40 pounds of air-dried soil in the various pots.*

Pot no.	Material added	Quantity added, grams	Pot no.	Material added	Quantity added, grams
1	Crotalaria	181.44	10	Cowpeas	181.44
2	Beggar-weed	181.44		$(NH_4)_2SO_4$	4.79
3	Natal grass	181.44	11	Manure	181.44
4	Cowpeas	181.44		$(NH_4)_2SO_4$	4.79
5	Manure	181.44	12	$(NH_4)_2SO_4$ (check)	4.79
6	Check, no treatment	———	13	Crotalaria*	181.44
7	Crotalaria	181.44	14	Beggar-weed*	181.44
	$(NH_4)_2SO_4$..........	4.79	15	Natal grass*	181.44
8	Beggar-weed	181.44	16	Cowpeas*	181.44
	$(NH_4)_2SO_4$	4.79	17	Manure*	181.44
9	Natal grass	181.44	18	Complete fertilizer only	
	$(NH_4)_2SO_4$	4.79		(check)	———

*Plus complete fertilizer { 4.79 grams ammonium sulfate; 13.31 grams superphosphate; 2.49 grams potassium sulfate

EXPERIMENTAL

EFFECT OF SOIL TREATMENTS UPON pH OF NORFOLK SAND

The pH was determined by the quinhydrone method. The determinations were made at the beginning of the experiment just after the soil had been treated but before any water had been added to the pots, and again 122 and 346 days after treatment. The results are expressed by curves in Figs. 1 and 2.

The results obtained at the beginning of the experiment show that the mere presence of organic matter reduced the pH below that of the virgin soil, except in the case of manure. The application of ammonium sulfate or complete fertilizers alone or in combination with the organic materials further reduced the pH. The addition of an ammonium sulfate-manure combination reduced the pH below that of the virgin soil, but the reduction was not as great as when only sulfate of ammonia was added. The pH value of all the soils treated with the complete fertilizer was reduced even to a greater extent than in the case of the soils to which ammonium sulfate alone was added.

Cowpeas, which contained the greatest percentage of nitrogen of all the organics used, had an apparent greater power to lower the pH than any of the other organic materials. This was true under either greenhouse or field conditions. Natal grass tended to raise the pH in a majority of instances under all conditions after the initial determination. This would lead one to believe that the carbon-nitrogen relationship influenced the pH of the soil. Only in a few instances was the pH of the soil at the different dates found to be lower than at the beginning of the experiment. There was a greater tendency at 346 days for a higher pH under greenhouse than under field conditions, which was favored by the presence of citrus seedlings.

EFFECT OF SOIL TREATMENTS UPON RESIDUAL NITROGEN CONTENT OF NORFOLK SAND

At the end of the investigation the soils kept in the open were sampled and the total nitrogen determined by the Gunning-Hibbard method (1). The results were figured on a moisture-free basis.

Only the results from the soils kept in the open are given as they are more representative of actual field conditions than the soils kept in the greenhouse. An examination of the curves given in Fig. 3 shows that at the end of the year there was a slight increase of residual

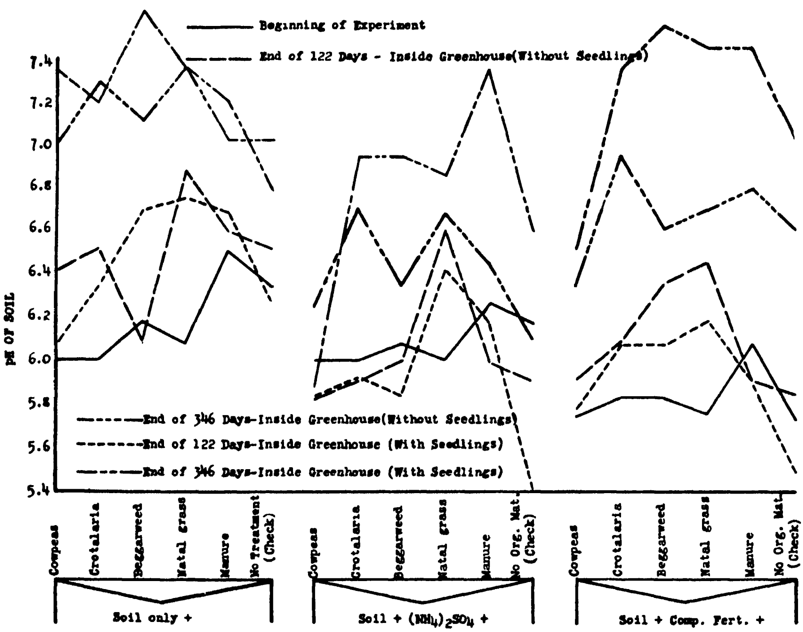

FIG. 1.—The effect of soil treatments upon the pH of Norfolk sand inside greenhouse.

nitrogen in every case where the soils had been treated with organic matter alone over that in the corresponding check soils. The uncropped soils, where inorganic salts were added in addition to the organic matter, also showed a slight increase in nitrogen when compared with the respective check soils. Ammonium sulfate and complete fertilizer, when added alone, apparently slightly increased the nitrogen content over that of the virgin soil. When added with organic matter no marked increase of nitrogen was noted.

EFFECT OF SOIL TREATMENTS UPON THE RESIDUAL ORGANIC MATTER OF NORFOLK SAND

As in the case of the residual nitrogen studies, only the soils under field conditions were used in this experiment. The method employed in determining the organic matter content of the soils was the loss on

ignition. The results were figured on a moisture-free basis and represented by the curves in Fig. 4.

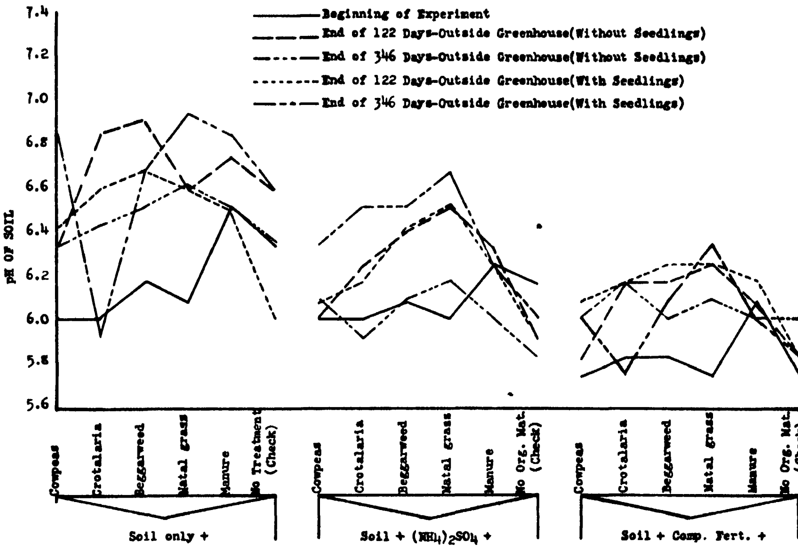

FIG. 2.—The effect of soil treatments upon the pH of Norfolk sand outside greenhouse.

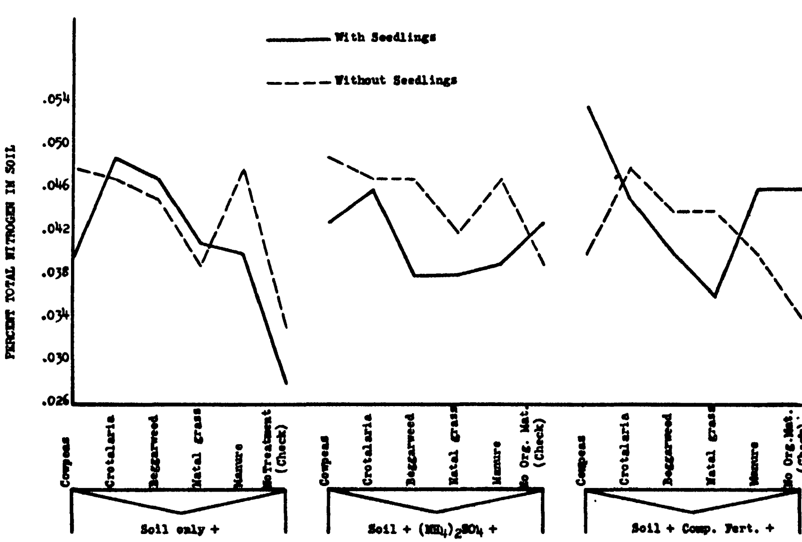

FIG. 3.—The effect of soil treatments upon the residual nitrogen content of Norfolk sand at end of 346 days.

It is evident that the addition of organic materials increased the amount of residual organic matter in the soil. The presence of citrus

seedlings were favorable to a greater accumulation of organic matter in the soil except where complete fertilizer was added.

EFFECT OF SOIL TREATMENTS UPON TOTAL DRAINAGE AND NITROGEN LOST FROM NORFOLK SAND

The Gunning method (1) modified to include the nitrogen of nitrates was followed for the determination of nitrogen, 50.0 cc of drainage water being used for a sample.

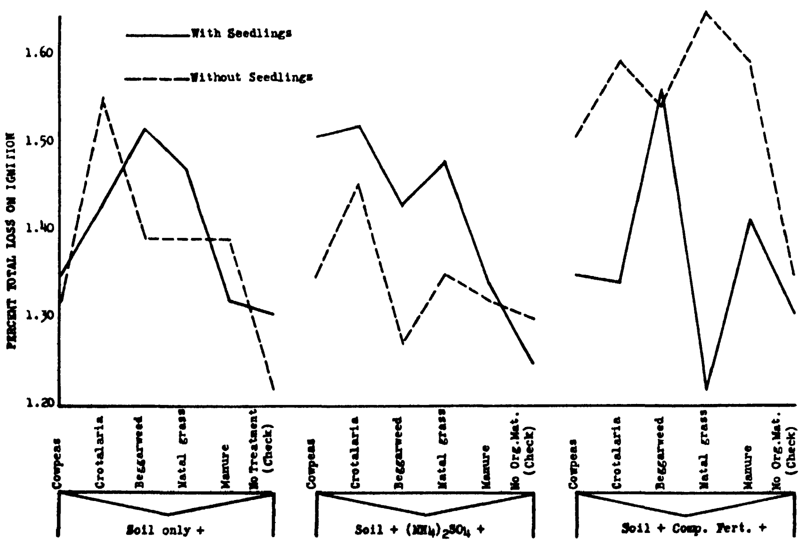

FIG. 4.—The effect of soil treatments upon the residual organic matter content of Norfolk sand at end of 346 days.

The curves presented in Fig. 5 give the total drainage from each soil during the period of the investigation and also the total nitrogen content of the drainage water expressed as grams lost per pot. As was to be expected, the curves show that the drainage from the fallow soils was greater than from those bearing seedlings. The addition of organic matter in the cropped soils reduced the amount of drainage water. There was, in general, an increase of drainage water from the fallow soils treated with organic matter. That there was a decreased loss of drainage in the cropped soil to which organic matter had been added, as against the checks of these series, may be explained by the increased growth of the seedlings in the presence of the organic matter. Judging from the amount of drainage from the fallow soils, the organic matter added at the beginning of the experiment had no effect upon the physical property of the soil in increasing its capacity for holding water at the end of 1 year.

There was a greater loss of total nitrogen from the fallow soils than from the cropped soils. This may have been due to a more concentrated solution, there being no seedlings present to utilize any of the

soluble nitrogen. The presence of the organic matter, however, had an influence upon the nitrogen of the drainage water. With those organic materials which contained the higher percentages of nitrogen, there was the greatest loss of nitrogen. The loss of nitrogen in the presence of the various materials given in descending order was as follows: Crotalaria, cowpeas, beggarweed or manure, and Natal grass. There was a greater loss in the check soils than in the soils to which Natal grass was added which shows that of the materials used Natal grass was the only one that seemed to conserve nitrogen. This was probably due to the utilization of the nitrogen by the organisms which decomposed the Natal grass.

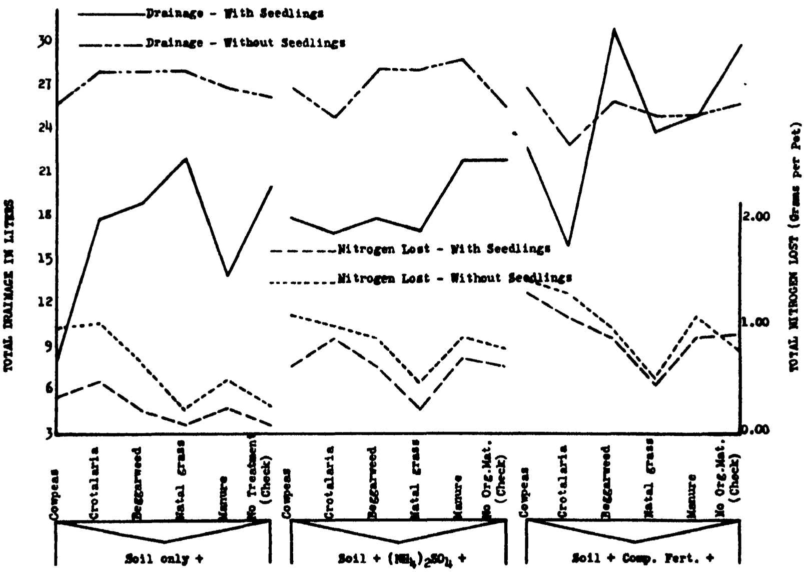

FIG. 5.—The effect of soil treatments upon the total drainage and nitrogen lost from Norfolk sand at end of 346 days.

EFFECT OF SOIL TREATMENTS UPON EXCHANGEABLE BASES (Ca, Mg, Na, AND K) OF NORFOLK SAND

The method employed in this work in the preparation of the base exchange solution was, with slight modifications, that used by Kelly and Brown (4) and as carried out in this laboratory was as follows: Fifty grams of the air-dried soil were placed in a 400-cc beaker. To this 350 cc of a normal NH_4Cl solution, heated to 90° C, were added and stirred at intervals until the solution had cooled to about room temperature; it was then filtered through a 15-cm filter. All the soil was then washed on the filter paper and the leaching continued, using cold normal NH_4Cl solution until 1000 cc had leached through the soil. Concentrated nitric acid was added to aliquots of this solution and evaporated to dryness to expel ammonium salts.

For the calcium, magnesium, sodium, and potassium the official methods (1) were followed. The results are expressed as milliequivalents of the cations per 100 grams of soil on a water-free basis.

In many soils the amount of water-soluble salts might be significant, but this was not the case in the Norfolk sand used in this investigation, so both the water-soluble and exchangeable forms were included as the exchangeable form. The data obtained in this experiment are presented in Table 2.

TABLE 2.—*The effect of soil treatment upon the exchangeable base content (Ca, Mg, Na, and K) of Norfolk sand.*

Soil treatment*	Milliequivalents per 100 grams soil									
	With seedlings					Without seedlings				
	Ca	Mg	Na	K	Total	Ca	Mg	Na	K	Total
Crotalaria	1.46	0.74	0.33	0.11	2.64	1.57	0.64	0.47	0.07	2.75
Beggarweed	1.64	0.85	0.39	0.09	2.97	1.68	0.74	0.54	0.06	3.02
Natal grass	1.78	0.95	0.37	0.12	3.22	1.71	0.74	0.46	0.11	3.02
Cowpeas	1.46	0.69	0.37	0.08	2.60	1.57	0.69	0.45	0.12	2.83
Manure	1.79	0.87	0.41	0.12	3.19	1.75	0.74	0.52	0.16	3.17
Soil only (check)	1.53	0.85	0.38	0.08	2.84	1.46	0.59	0.45	0.12	2.62
Crotalaria + $(NH_4)_2SO_4$	1.28	0.85	0.40	0.09	2.62	1.43	0.59	0.43	0.12	2.57
Beggarweed + $(NH_4)_2SO_4$	1.46	0.74	0.39	0.08	2.67	1.46	0.54	0.46	0.13	2.59
Natal grass + $(NH_4)_2SO_4$	1.46	0.69	0.42	0.09	2.66	1.46	0.59	0.44	0.12	2.61
Cowpeas + $(NH_4)_2SO_4$	1.28	0.69	0.41	0.08	2.46	1.57	0.49	0.47	0.12	2.65
Manure + $(NH_4)_2SO_4$	1.46	0.74	0.50	0.08	2.78	1.39	0.59	0.98	0.15	3.11
$(NH_4)_2SO_4$ (check)	1.21	0.69	0.56	0.11	2.57	1.25	0.49	0.63	0.12	2.49
Crotalaria + comp. fert.	1.18	0.54	0.27	0.05	2.04	1.61	0.59	0.52	0.12	2.84
Beggarweed + comp. fert.	1.21	0.49	0.28	0.04	2.02	1.71	0.64	0.50	0.12	2.97
Natal grass + comp. fert.	1.32	0.44	0.33	0.07	2.16	1.89	0.69	0.52	0.12	3.22
Cowpeas + comp. fert.	1.03	0.54	0.42	0.16	2.15	1.61	0.59	0.52	0.11	2.83
Manure + comp. fert.	1.21	0.44	0.32	0.17	2.14	1.79	0.64	0.38	0.11	2.92
Complete fertilizer (check)	1.14	0.39	0.39	0.20	2.12	1.46	0.54	0.48	0.12	2.60

*Soils analyzed at end of experiment.

A study of these data shows that the addition of organic matter tended to increase the exchangeable calcium and magnesium content in both fallow and cultivated soils when compared with the respective checks. The soils to which ammonium sulfate or the complete fertilizer were added, with few exceptions, contained less exchangeable calcium than those not treated with these materials. This fact may be due to the rise of acidity at the beginning of the experiment (Fig. 1) which probably caused the calcium to become soluble and more readily leached from the soil. The inconsistency noted in the case of the fallow soils to which the complete fertilizer was added was probably due to the absence of seedlings which would naturally utilize some of the calcium which was added in in the fertilizer. There was almost invariably more calcium, sodium, and potassium in the fallow soils. The fallow soils treated with the complete fertilizer were the only ones in which the total bases consistently exceeded those in the cropped soils.

From the individual treatments, it appears that the soils to which Natal grass or manure had been added contained, in most cases, more exchangeable calcium. The least amount of calcium was found in the soils treated with cowpeas and Crotalaria. When it is considered that of all the organic materials used the cowpeas and Crotalaria contained the largest amounts of nitrogen, it seems probable that this increased nitrogen was responsible for the loss of calcium. After oxidation to nitric acid it combined with the soil calcium and subsequently was leached from the soil.

Although the fallow soils uniformly contained more sodium and potassium than the cropped soils, the addition of organic matter failed to increase these constituents consistently. The only significant relationship of the divalent ions to the univalent is that the divalent ions are always in excess. This is in accord with results reported by Barnette and Hester (2).

EFFECT OF SOIL TREATMENT UPON BASES LOST IN DRAINAGE WATERS FROM NORFOLK SAND

One hundred cc of a composite sample of drainage water were used and calcium, magnesium, sodium, and potassium determined as in the case of the base exchange solution.

The data presented in Table 3 give the amounts of bases lost from Norfolk sand through drainage water. As in the case of nitrogen in the drainage water, more total bases were lost from the fallow soils. The loss both in the fallow and cropped soils, with few exceptions, was increased by the addition of organic matter. The addition of ammonium sulfate or a complete fertilizer, without organic matter, increased the loss of total bases to a greater extent than when the organic materials were used alone with the exception of the fallow check soil where ammonium sulfate alone was added. In this instance there was a greater total loss from the fallow soils treated with Crotalaria, beggarweed, or cowpeas alone than from the soil treated with ammonium sulfate alone. The combination of ammonium sulfate, or complete fertilizer, with the organic materials further increased this loss. The greatest loss occurred where the complete fertilizer was used with the organic materials. This was probably due to the soluble salts added in the complete fertilizer. These results would indicate that the loss of plant food from this soil through drainage water was dependent upon the quantity of soluble plant food present. Not only does the total quantity of plant food present in the soil influence the total amount lost, but the relationships among the various constituents making up the total may have an influence.

The loss of bases was apparently greater from those soils to which the greater quantity of nitrogen had been added. This would indicate that the nitrogen present in a soil influences the loss of bases from that soil. In the fallow soils, the loss from those soils to which Natal grass had been added was less than from the soils treated with any of the other organic materials, but greater than from the check soils. The cropped soils to which a combination of Natal grass and ammonium sulfate or Natal grass and the complete fertilizer was added lost less total bases than did the check soils of these series. The

TABLE 3.—*The effect of soil treatments upon the bases lost in drainage water from Norfolk sand*

Soil treatment	Grams lost per pot									
	With seedlings					Without seedlings				
	CaO	MgO	Na_2O	K_2O	Total	CaO	MgO	Na_2O	K_2O	Total
Crotalaria	1.57	0.69	1.16	1.02	4.44	2.14	1.03	1.11	1.76	6.04
Beggarweed	1.02	0.47	0.73	0.80	3.02	1.85	0.94	1.07	1.46	5.32
Natal grass	1.19	0.54	1.01	0.99	3.73	0.81	0.56	1.12	1.26	3.75
Cowpeas	0.56	0.21	0.29	0.13	1.19	3.20	1.56	1.09	1.50	7.35
Manure	0.81	0.45	0.88	1.01	3.15	1.38	0.90	1.18	1.54	5.00
Soil only (check)	0.84	0.38	0.68	0.08	1.98	1.32	0.56	0.95	0.20	3.05
Crotalaria+$(NH_4)_2SO_4$	2.07	0.88	0.77	1.43	5.15	3.40	1.34	1.17	1.86	7.77
Beggarweed+$(NH_4)_2SO_4$	2.08	0.85	0.90	0.95	4.78	3.40	1.46	1.23	1.71	7.80
Natal grass+$(NH_4)_2SO_4$	1.91	0.81	0.84	0.91	4.47	2.34	1.11	1.49	1.30	6.24
Cowpeas+$(NH_4)_2SO_4$	3.40	1.44	0.90	1.28	7.02	3.34	1.53	1.12	1.32	7.31
Manure+$(NH_4)_2SO_4$	2.44	1.08	1.12	1.45	6.09	2.94	1.44	1.34	2.11	7.83
$(NH_4)_2SO_4$ (check)	3.11	0.86	0.97	0.22	5.16	3.05	0.97	0.81	0.30	5.13
Crotalaria+comp fert	4.66	1.30	1.28	2.50	9.74	5.65	1.44	0.96	2.91	10.96
Beggarweed+comp fert	4.90	1.55	1.15	2.05	9.65	5.94	1.46	1.36	2.44	11.20
Natal grass+comp fert	4.93	1.44	0.46	2.05	8.88	4.65	1.35	1.21	2.31	9.52
Cowpeas+comp fert	5.71	1.83	1.08	2.15	10.77	6.75	1.93	1.77	2.41	12.86
Manure+comp fert	5.31	1.63	1.22	2.62	10.78	5.31	1.70	1.33	3.22	11.56
Complete fertilizer (check)	5.71	1.18	0.91	1.15	8.95	5.20	1.09	0.83	1.20	8.32

difference was very small, and hence it may be concluded that the addition of organic matter again failed to show any favorable influence for the conservation of the total plant food in these soils from loss through leaching.

When the individual bases are considered, it is apparent that the addition of ammonium sulfate only, or the complete fertilizer only, increased the loss of calcium over that lost from the untreated soil. The presence of organic matter tended to reduce this loss from the cultivated soils. With the other bases there was a greater loss, with few exceptions, from the soils containing organic matter than from the corresponding checks. In general, there was a greater loss of potassium than sodium or magnesium from the fallow soils to which organic matter alone or with the inorganic salts had been added. Similar results were obtained with the cropped soils to which ammonium sulfate, or the complete fertilizer, had been applied in combination with organic matter. The loss of magnesium from all the soils to which the complete fertilizer had been applied exceeded that of sodium.

EFFECT OF SOIL TREATMENTS UPON RELATION OF CALCIUM TO POTASSIUM IN DRAINAGE WATERS FROM NORFOLK SAND

Since Pierre (5), Ruprecht (6), and others found a correlation between the ratio of calcium to potassium in the soil solution, it seemed desirable to determine what this relationship was in the drainage waters in these tests. The data secured and presented in the form of curves in Fig. 6 were calculated from the results given in Table 3.

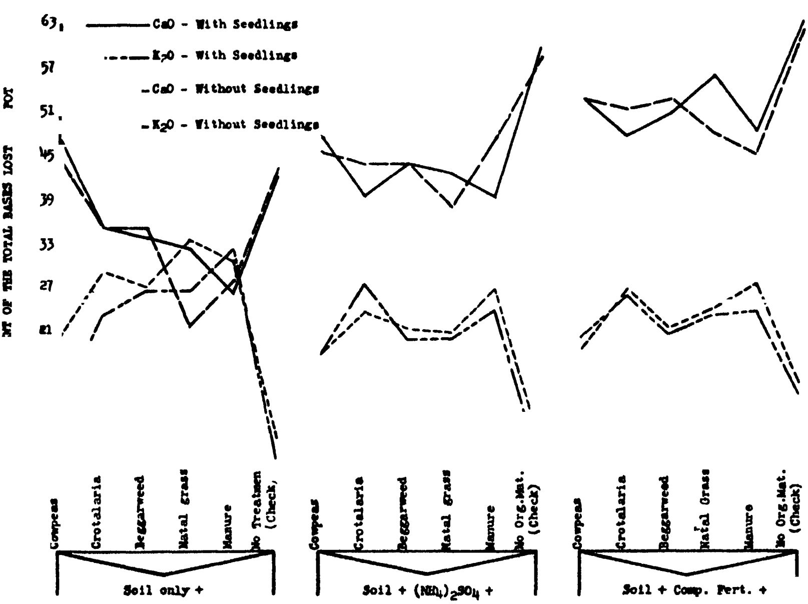

FIG 6.—The effect of soil treatments upon the calcium-potassium ratio in drainage waters from Norfolk sand.

These curves represent the percentage of calcium and potassium in the total bases leached.

It appears from these curves that the amount of divalent ion in the drainage water greatly exceeded the amount of the monovalent. The percentage of monovalent ion was greater in the drainage water from the fallow soil, however, than in that from the cropped soils, while the divalent ion varied considerably in the two cases. The application of ammonium sulfate, whether alone or in combination with organic matter, increased the percentage of calcium in the drainage in practically all cases. The complete fertilizer which contained both ammonium sulfate and calcium further increased this loss of calcium, which was expected.

These curves show a significant relationship between calcium and potassium. Where there was an increase of calcium there was almost always a decrease in potassium, even in the drainage waters from the soils to which complete fertilizer had been applied. The greatest amount of total calcium was lost from the soils which had been treated with the organic materials containing the greatest quantity of total nitrogen, but the proportion of calcium to potassium in the drainage waters from these soils was less. Apparently, as the quantity of calcium in the drainage water increased, that of potassium decreased.

SUMMARY AND CONCLUSIONS

Experiments were conducted to study the influence of various organic materials, inorganic fertilizers, and environmental conditions on the pH of the soil, on the amount of exchangeable bases present, and on the residual nitrogen and organic matter in Norfolk sand. Studies were also made relative to the quantity and composition of drainage waters from the soils variously treated. From data gathered calculations were made to determine the relation of calcium to potassium in the total bases in the drainage waters. The results of these studies may be summarized as follows:

1. The addition of freshly ground, dried organic matter to Norfolk sand reduced the pH of the soils at the beginning of the experiment below that of the virgin soil. The application of ammonium sulfate further reduced the pH and the soils treated with complete fertilizer were reduced in pH to a greater extent than in the case of the ammonium sulfate treated soils. There was a gradual increase of the pH from the beginning to the end of the experiment.

2. The addition of the various organic materials caused a slight increase in the residual nitrogen in the soils after 1 year. The addition of inorganic nitrogenous fertilizer with these organic materials in cropped soils caused a slight loss of nitrogen when compared with those soils to which only organic matter had been applied. In those cropped soils to which inorganic nitrogenous fertilizers were added alone there was an increase in the nitrogen over that found in the untreated check.

3. The application of organic matter caused an increased residual organic matter content at the end of the experiment. There was apparently little difference in the kind of organic materials used in affecting this increase.

4. The application of organic matter to the soil apparently had little effect upon the amount of drainage water lost from Norfolk sand over a period of 1 year. More drainage water and total nitrogen were lost from the fallow than from the cropped soils and the quantity of nitrogen lost depended upon the amount added to the soil.

5. The addition of organic matter increased the exchangeable calcium and magnesium content in both the fallow and cropped soils over the respective checks. All the soils to which ammonium sulfate was added contained less exchangeable calcium than those soils not treated with this material. Additions of complete fertilizer to the soils kept fallow increased the exchangeable calcium. Apparently, the presence of nitrogen reduced the amount of exchangeable calcium in the soil. The fallow soils contained more exchangeable sodium and potassium than did the cropped soils.

6. As in the case of nitrogen, more total bases were lost through drainage from the fallow soils. The loss of total bases was increased by the addition of organic matter and applications of inorganic fertilizers increased their loss. The loss of bases was greatest from the soils to which the greater quantity of nitrogen was added. With the fallow soils, the loss of total bases from the soils to which Natal grass had been added was less than from soils treated with any of the other organic materials, but the difference was small. Even here the loss was greater than in the check soils, so that the addition of organic matter failed to show any favorable influence on the retentive power of Norfolk sand as determined in this investigation. The soils to which ammonium sulfate had been added showed the greatest loss of calcium, but the presence of organic matter tended to reduce this loss. The addition of organic matter seemed to cause a greater loss of sodium and potassium.

7. The divalent calcium ion occurred in greater amounts than the monovalent sodium or potassium in the soil as well as drainage water. This condition might have been due to a greater amount of the element calcium being present at the beginning of the experiment. The monovalent ions were of greater quantity in the drainage water from the fallow soils than in the water from the cropped soils, but the quantity of divalent calcium ion was about the same in the two cases. A greater quantity of the divalent magnesium ion was found in exchangeable form in the cropped soils, except where complete fertilizer was added. In the case of drainage waters this was reversed. There was a significant relationship between calcium and potassium in the drainage waters. As the proportion of calcium in the total bases increased, the proportion of potassium decreased.

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ERRATUM

TWO typographical errors occur in the article by Dr. H. H. Love in the October number of the JOURNAL, both on page 809. In the first formula on that page, r should be written as a subscript to σ (σ_r) rather than as an exponent. Also, in the sentence beginning "The formula for σ_2....", the subscript of σ should be z and not 2.

AGRONOMIC AFFAIRS

REORGANIZATION OF AMERICAN SOIL SCIENTISTS

THE following statement has been prepared by Dr. Richard Bradfield on behalf of a joint committee representing the Soils Section of the American Society of Agronomy, the American Soil Survey Association, and the American Section of the International Society of Soil Science appointed at the annual meetings of these organizations in Washington in November, 1934. The recommendations made by this Committee will be considered in an open meeting at Chicago on the evening of December 4 next.

I. RECENT ACTIVITIES

The expansion of interests in the American Society of Agronomy, the American Soil Survey Association and the International Society of Soil Science within the last decade has resulted in considerable duplication of effort and some working at cross purposes. This has been realized by the members of these organizations and much thought has been given to possible solutions.

1. *In American Society of Agronomy.*—In 1930 the American Society of Agronomy appointed a committee to study plans for its reorganization. (Jour. Amer. Soc. Agron., 22: 1054. 1930.) This committee recommended in 1931 the reorganization of the Society on a sectional basis with a (1) Crops Section and a (2) Soils Section, each Section to be allowed to form "such subsections as it sees fit". (Jour. Amer. Soc. Agron., 23: 1032–34. 1931.) Provision was also made for two committees to formulate plans for the operation of each Section.

The committee for organizing the Soils Section (M. F. Miller, *Chairman*, M. F. Morgan, S. A. Waksman, and R. I. Throckmorton) submitted a report which was adopted and published in the Jour. Amer. Soc. Agron., 24: 1010–11, 1932. The new constitution is published in the Jour. Amer. Soc. Agron., 24: 839–841, 1932. Modifications made in the constitution before final adoption are to be found on page 1026 of the same volume of the JOURNAL.

The By-Laws of the Soils Section of the American Society of Agronomy provided (*loc. cit.*, page 1011) that "the Section shall function as the American Section of the International Society of Soil Science, but only those members paying the regular dues to the International Society shall have a vote in matters pertaining to it". After the adoption of this provision the objection was raised that the Soils Section of the American Society of Agronomy had no authority to set itself up "to function as the American Section of the International Society of Soil Science".

2. *In American Soil Survey Association.*—All the activities discussed thus far were in the Agronomy Society. At the meeting of the American Soil Survey Association in Chicago in 1931 "there was manifested considerable sentiment toward changing the name of the organization to the American Soil Science Association", as it was felt that the organization had outgrown its original name. Definite action was deferred. A questionnaire indicated that over 60% of the members were in favor of this change in name.

3. *Joint action.*—In view of these "sentiments" among the members of these three soil science organizations, a joint meeting of all men interested in soil science, whether a member of any, all, or none of the existing organizations, was held in Chicago at the time of the regular meetings of the American Soil Survey

Association and the American Society of Agronomy in November 1933. At this meeting a motion was passed providing that a committee consisting of (1) the Chairman and Secretary of the Soils Section of the American Society of Agronomy, (2) the President and Secretary of the American Soil Survey Association, and (3) the past President (Dr. J. G. Lipman) and the American Secretary of the International Society of Soil Science be requested to examine critically the constitution and by-laws of the Soils Section of the American Society of Agronomy and recommend such changes as seem desirable in order to provide:

1. For a single association of soil scientists, organized on a sectional basis similar to the International Society of Soil Science which shall function as the American Section of the International Society of Soil Science.

2. That the desirable features of the present associations be preserved in so far as it is possible.

3. That a copy of the recommendations of this joint committee be sent to every member of (1) the International Society of Soil Science in America, (2) the American Soil Survey Association, (3) the Soils Section of the American Society of Agronomy, and (4) to any other large organization of soil scientists in America which the committee desires to consider, not later than September 1934.

4. That the recommendations of this committee be considered first at a meeting to which all persons interested in soil science are invited to participate, such meeting to be held in Washington, D. C., at the time of the annual meeting of the American Soil Survey Association and the American Society of Agronomy.

5. That the final form of the recommendations adopted by this joint session be referred to the separate organizations for ratification.

In a report published in the Jour. Amer. Soc. Agron., 26: 806, 1934, this joint committee states that they were "unable to formulate any satisfactory plan or to agree on any form of a single association of soil scientists and accordingly no recommendation for the organization of such an association is presented". The committee did agree that it would be desirable to establish an American Section of the International Society of Soil Science and recommended a form of organization which was adopted in Washington in November, 1934. (See Jour. Amer. Soc. Agron., 27, 321, 1935, for details.) Thus, the committee instructed to draw up plans for bringing the soils scientists together in a single association were in the end responsible for the creation of an additional organization!

They recommended that a new committee be appointed to continue the effort to draw up plans for a "single association of soil scientists" in accordance with the motion passed at Chicago in 1933. This recommendation was approved and the following joint committee appointed:

A. L. Patrick and A. M. O'Neal,
Representing the American Soil Survey Assoc.

S. A. Waksman and M. F. Morgan,
Representing the International Society of Soil Science.

C. F. Shaw and R. Bradfield,
Representing the Soils Section of the American Society of Agronomy.

This communication is an effort by the above committee to find a solution to the problem.

II. THE NEED FOR A SINGLE SOIL SCIENCE ORGANIZATION

1. *Memberships overlap.*—The conditions which have led to the discussion and actions shown above have grown out of the over-lapping in membership and activities of the existing organizations. Detailed data on membership are ap-

pended. From these data it is apparent that almost one-third of the members of the Soils Section of the A. S. A.[1] are also members of the A. S. S. A. and almost half the members of the A. S. S. A. are also members of the Soils Section of the A. S. A. The over-lapping is actually even greater than these figures indicate because of the fact that most of the 125 men who are members of both organizations are active in both, while many who are members of only one seldom take any active part in either. The ease with which a meeting of one group can be transformed into the other, which in recent meetings has been largely a matter of changing presiding officers, is further evidence of how close these organizations have already grown together.

2. *Programs overlap.*—An analysis of the papers presented before the two groups shows that about half are of as much interest to one group as the other. (See table.) There has been a fine spirit of cooperation existing between the organizations the last few years but this cooperation has been due to the personal efforts of the officers. There is no provision in the by-laws of either organization to insure cooperation or to eliminate duplication. Each group normally proceeds independently of the other.

3. *Present system is unnecessarily complicated and expensive.*—It is evident that two organizations in which there is such an over-lapping of membership and interest would not function as efficiently nor as economically as a single well-coordinated organization. A single organization receiving the united support of the soil scientists of the country will have less overhead and hence will be able to devote a larger proportion of its funds and of the energy of its members to more productive efforts.

4. *Publications.*—Our publications can be improved, their circulation increased, and their prestige enhanced, both at home and abroad, if they are given the united support of the workers in this country. At present most of the papers on the A. S. S. A. program are printed in the annual BULLETIN. It contains however less than half of the soil science papers presented at the annual meetings. The rest are either scattered through several numbers of the JOURNAL of the A. S. A. or some other journal, or are not published at all. It would be a great convenience to have all the soil science papers published together in an annual volume of PROCEEDINGS.

The BULLETIN has a circulation of a little over 300. It is not as well known either at home or abroad as it should be. Papers published in it have not been abstracted by many of the abstract journals, consequently papers published in it have been frequently overlooked by other investigators.

If the soil scientists in the United States unite they could unquestionably make a success of a volume of PROCEEDINGS.

[1]Hereafter, the following abbreviations will be used in this communication: A. S. A. for American Society of Agronomy; A. S. S. A. for American Soil Survey Association; I. S. S. S. for International Society of Soil and Science; and S. S. S. for the proposed new "Society of Soil Science".

Distribution of Memberships in the Three Soils Science Organizations in the United States, 1935

Total members (U S), A S A	. 768*
Total members (U S), A S S A	270†
Total members (U S), I S S S	114‡
Members of both A S A and A S S A	125
Members of A S A, A S S A, and I S S S	37
Members of A S A and I S S S	28
Members of A S S A and I S S S	16
Total members I S S S in A S A	65
Total members I S S S in A S S A	. 53
Members of I S S S who are members of neither A S A or A S S A	34

*Based on list received from P E Brown Sec, Jan 11 1935
† " " A L Patrick Sec Feb 4 1935
‡ " " C F Shaw Dec 22 1934

PERCENTAGE OF TOTAL NUMBER OF SOILS MEN IN DIFFERENT ORGANIZATIONS

(Assuming one-half of A S A members are interested primarily in soils)

One-half American members of A S A	384
Members of A S S A who are not members of the A S A	145
Members of the I. S S S who are members of neither A S A nor A S S A	34

Total number of soils men in all three present organizations
Percentage total in A S A
Percentage total in A S S. A
Percentage total in I S S S
Percentage total in both A S A and A S S A
Percentage members Soils Section, A S A in A S S A
Percentage members A S S A in Soils Section of A S A
Percentage members I S S S in A S A

Distribution of Papers on Programs of A S A and A S S A in 1933 and 1934

	1933		1934	
A S S A	—	21*	—	41*
A S A	—	28	—	41
Biology Section	20	—	16	—
Fertility Section	4	—	10	—
Fertility and Chemistry Sections	4	—	7	—
Physics	—	—	8	—
Joint A S S A and A S A	—	21	—	14
Chemistry Section and A S S A	6	—	5	—
Physics Section and A S S A	6	—	—	—
Land Use and A S S A	9	—	—	—
Fertility and Crops Section	—	—	9	—
Total Soils Papers	—	70	—	96
A S A Crops Section (in addition to joint sessions)	—	22	—	23
General, A S S A and A S A	—	5	—	3
Total number papers on programs	—	97	—	122
Number papers published in A S S A Bulletin	—	33	—	40
Percentage soils papers published in A S S A Bulletin	—	47	—	41 5

*Ten of the 21 papers in 1933 and 12 of 41 papers in 1934 were of equal interest and value to the Soils Section of the A S A

III. HOW CAN THE DESIRED IMPROVEMENTS BE AFFECTED WITH THE LEAST DISTURBANCE TO PRESENT ARRANGEMENTS?

The almost unanimous approval given the resolution adopted at the joint meeting in Chicago in 1933 and again in Washington in 1934, clearly indicates that the great majority of soil scientists favor the formation of a single soil science society organized on a sectional basis similar to the I. S. S. S.

Several methods for bringing about such an organization have been proposed and discussed. Last year's Committee on Reorganization considered the possibility of forming an entirely new organization but in the end rejected the plan by a large majority. It has also been proposed that one or the other of the existing organizations should expand and become the American organization quite independently of the other. This plan would result in even more duplication and would have other undesirable consequences. Since there is so much overlapping in membership and interests at the present time, the Committee feels that the only logical solution is a merging of the two existing organizations (A. S. S. A. and the Soils Section of A. S. A.) to form a new Soil Science Society (S. S. S.).

The next question is, What relation shall the new S. S. S. have to the A. S. A.? All who have been approached with this question, whether members of the A. S. A. or not, feel that the close affiliation between the crops and soils groups which has existed in the A. S. A. should be continued. Soil science is now recognized throughout the world as a distinct science. Many feel for that reason that the new organization should be known as a Soil Science Society. For a reorganization committee to ignore this feeling is to invite failure. There seems to be no reason why a new Soil Science Society formed by fusing the A. S. S. A. and the Soils Section of the A. S. A. should not continue to function as the "Soils Division" of the A. S. A. In fact, such an arrangement should prove mutually advantageous.

Your Committee therefore recommends[2].

1. THAT THE A. S. S. A. AND THE SOILS SECTION OF THE A. S. A. UNITE TO FORM A SINGLE ORGANIZATION WHICH SHALL BE CALLED
   (1) SOILS SCIENCE DIVISION OF THE A. S. A.
   (2) AMERICAN ASSOCIATION OF SOIL SCIENTISTS
   (3) AMERICAN SOCIETY OF SOIL SCIENCE (This group will be referred to hereafter as the S. S. S.)

THIS ORGANIZATION SHALL ALSO SERVE AS THE SOILS SCIENCE DIVISION OF THE A. S. A. IN ACCORDANCE WITH THE PROVISIONS OF THE REVISED CONSTITUTION OF THE A. S. A.

2. THAT IN VIEW OF THE WIDESPREAD INTEREST IN EROSION CONTROL AND OTHER TECHNICAL APPLICATIONS OF SOIL SCIENCE THAT A NEW SECTION, SECTION VI, BE FORMED TO FURTHER THE WORK OF THIS GROUP.
3. THAT THE VARIOUS FIELDS OF INTEREST IN BOTH ORGANIZATIONS BE ALLOCATED TO THE PROPER SECTION IN THE NEW ORGANIZATION AND THAT THIS DIVISION OF SUBJECT MATTER FOLLOW AS CLOSELY AS POSSIBLE THE SCHEME USED BY THE INTERNATIONAL SOCIETY OF SOIL SCIENCE.

[2]All recommendations are printed in capital letters.

I. Physics, II. Chemistry, III. Biology, IV. Fertility, V. Morphology, and VI. Technology—or Conservation. (Including erosion control, drainage, irrigation, earth construction problems, highway foundations, etc.)

It is believed that each of these groups should be formed to further the specialized work in each field. It is realized at the same time that much of the work of these specialized groups is also of interest to those in other groups. This plan will provide opportunity for the various specialists to consider in their sectional meetings those problems of technic, etc., which are peculiar to that group alone. Subjects of interest to more than one group should be discussed before joint meetings of all sections concerned.

By arranging some of the specialized sectional meetings on the first day, the others on the last day, and the joint programs of more general interest in the middle of the week, members interested in the activities of one group only would be able to attend all the meetings of interest to them in two or three days, while those with more diversified interests could remain for the entire program. The aim should be to enable every one to hear as many as possible of the papers of interest to him with the least possible loss of time from his regular work.

The time required for the programs of the various sections will vary widely. No attempt should be made to standardize their length. Some sections may prefer to meet only every other year; others may find one or two half-day sessions ample, while others may require five or six.

OFFICERS OF THE S. S. S.—THE OFFICERS OF THE S. S. S. SHALL CONSIST OF A (1) PRESIDENT AND A (2) SECRETARY. THE SECRETARY SHALL BE ELECTED AT EACH ANNUAL MEETING TO SERVE UNTIL THE CLOSE OF THE NEXT, WHEN HE AUTOMATICALLY BECOMES PRESIDENT.

THE PRESIDENT SHALL PRESIDE AT THE MEETINGS OF THE S. S. S., SERVE AS CHAIRMAN OF ITS EXECUTIVE COMMITTEE, AND SHALL REPRESENT IT ON THE EXECUTIVE COMMITTEE OF THE A. S. A. HE SHALL SERVE AS A COORDINATOR OF THE VARIOUS SECTIONAL PROGRAMS AND, WITH THE ASSISTANCE OF THE EXECUTIVE COMMITTEE, ORGANIZE GENERAL SOIL SCIENCE PROGRAMS WHEN DESIRABLE.

IN ADDITION TO THE USUAL DUTIES OF HIS OFFICE, THE SECRETARY SHALL SERVE ALSO AS VICE-PRESIDENT AND SHALL SUCCEED TO THE PRESIDENCY THE FOLLOWING YEAR.

THE EXECUTIVE COMMITTEE OF THE S. S. S. SHALL CONSIST OF THE PRESIDENT AND SECRETARY AND THE CHAIRMAN OF EACH OF THE SECTIONS OR COMMISSIONS.

OFFICERS OF SECTIONS OR COMMISSIONS.—THE OFFICERS OF EACH SECTION SHALL BE (1) A CHAIRMAN AND (2) A SECRETARY. THE SECRETARY SHALL BE ELECTED AT EACH MEETING TO SERVE UNTIL THE CLOSE OF THE NEXT, WHEN HE AUTOMATICALLY BECOMES CHAIRMAN.

DUTIES OF OFFICERS OF SECTION OR COMMISSION. — THE CHAIRMAN SHALL (1) PRESIDE AT ALL MEETINGS, (2) BE RESPONSIBLE FOR THE ORGANIZATION OF THE PROGRAM OF HIS SECTION, AND (3) SERVE ON THE EXECUTIVE COMMITTEE OF THE S. S. S. THE SECRETARY SHALL (1) KEEP THE MINUTES OF THE ANNUAL BUSINESS MEETING AND REPORT SAME TO THE SECRETARY OF THE S. S. S., (2) COLLECT THE MANUSCRIPTS OF ALL PAPERS

READ BEFORE THE SECTION AND FORWARD THEM TO THE EDITOR FOR PUBLICATION IN THE PROCEEDINGS, (3) PRESIDE IN THE ABSENCE OF THE CHAIRMAN, AND (4) SUCCEED TO THE CHAIRMANSHIP OF THE SECTION.

PUBLICATIONS.—THE S. S. S. SHALL PUBLISH AN ANNUAL VOLUME OF PROCEEDINGS WHICH WILL INCLUDE ALL OF THE PAPERS PRESENTED AT ITS ANNUAL MEETING AND A REPORT OF ALL BUSINESS TRANSACTED. THIS VOLUME SHOULD BE PUBLISHED AS SOON AS POSSIBLE AFTER THE MEETING.

(The present committee represents the soil science groups only; the publication of crops papers presented at the annual meeting is a matter to be acted on by that group separately.)

This publication would take the place of the BULLETIN of the A. S. S. A. The BULLETIN has been paying its way on a $2.00 membership fee and a circulation of only 300. The JOURNAL of the A. S. A. has a circulation of about 1,500. With the united backing of all the soils men in the United States, it should be possible to build up a circulation of at least 1,000 for a volume of PROCEEDINGS. The advantages of having all the soil science papers published promptly after the meetings and together in one convenient volume is evident.

The editor of the JOURNAL of the A. S. A. states that he will probably publish 116 papers in 1935 of which 14 were soils papers presented at the annual meetings last fall. It is evident that the publication of these 14 papers in a volume of PROCEEDINGS would not seriously weaken the JOURNAL. In fact it would permit the JOURNAL to devote more of its space to contributed papers and would enable it to remove some of the present restrictions. The change should not greatly alter the subscription list of the JOURNAL as there are not many subscribing to the JOURNAL merely to get the 14 papers which, under the proposed plan, would be published in the PROCEEDINGS.

The title "Bulletin of the A. S. S. A." is misleading to one not acquainted with it. Its appeal is limited largely to those engaged in soil survey work.

There are probably more soil scientists in the United States than in any other country with the possible exception of the U. S. S. R. The PROCEEDINGS of the American Society of Soil Science published with the united backing of all American soil scientists would seem certain to receive more support both at home and abroad than the present BULLETIN which it would supercede.

Dues.—A cursory examination of the data cited above on membership in the present organizations indicates that a few are members of only one organization, many are members of two, and many others are members of at least three different soils organizations.

If it is to be acceptable to a group with such diversified interests the plan of reorganization, especially the system of dues, must be kept flexible. Opportunity for membership and limited participation should be provided at a relatively low sum. In order to encourage subscriptions and support for all of the activities and publications, a just system of club rates should be provided. Such a plan is now being used with success by the American Chemical Society, the Institute of Physics, and other scientific organizations.

The following scheme is proposed for adoption by the S. S. S. The exact cost of printing a volume of PROCEEDINGS is, of course, not known. It will depend on the number of volumes printed, the style of printing, etc. If it contains all the papers presented instead of the usual 40 to 50% published in the BULLETIN, the cost will be somewhat higher than that of the BULLETIN of the A. S. S. A.,

but should be considerably less than twice as much because of the enlarged circulation

The Committee recommends therefore:

THE ADOPTION OF AN ELECTIVE SYSTEM OF DUES AND SUBSCRIPTIONS WITH REDUCTIONS TO THOSE SUBSCRIBING FOR ONE OR MORE OF THE PUBLICATIONS. THE FOLLOWING SCHEDULE IS GIVEN AS AN ILLUSTRATION OF THE PRINCIPLE PROPOSED. THE EXACT CHARGES MAY HAVE TO BE CHANGED.

MEMBERSHIP IN S. S. S.	$1.00
MEMBERSHIP AND PROCEEDINGS	4.50
MEMBERSHIP AND JOURNAL	5.00
MEMBERSHIP, PROCEEDINGS, AND JOURNAL	9.00
MEMBERSHIP AND I. S. S. S. Amer. Sect. dues 50c; I. S. S. S. dues $5.00	5.50
MEMBERSHIP, PROCEEDINGS, JOURNAL, AND I. S. S. S.	14.00

Collection of Dues.—At the present time there is much "lost motion" and unnecessary expense in connection with the collection of dues, printing, and distribution of programs. In recent years, both the A. S. A. and the A. S. S. A. have printed the complete soils program of both organizations. This has been appreciated by the men who were members of only one organization and has been decidedly worth while. It has been an unnecessary expense, however, as 125 men received two programs. At the present, calls for dues are sent out as follows:

By the Secretary of the A. S. A.	$5.00
By the Secretary of the A. S. S. A.	2.00
By the Secretary of the I. S. S. S. (7.5 guilders)	5.00
By the Secretary of the Amer. Sect. I. S. S. S.	.50
	$12.50

A separate reply and a separate check is necessary for each. These are all small items, of course, but in the aggregate they would make a substantial contribution to our publication program.

We recommend therefore:

1. THAT THE SECRETARY-TREASURER OF THE AMERICAN SOCIETY OF AGRONOMY BE REQUESTED TO RECEIVE ALL DUES.
2. THAT THE SECRETARY-TREASURER OF THE AGRONOMY SOCIETY DISTRIBUTE EACH YEAR ABOUT ONE MONTH IN ADVANCE OF THE ANNUAL MEETING TO EACH MEMBER A PROGRAM LISTING *ALL* PAPERS TO BE PRESENTED AT THE ANNUAL MEETING TOGETHER WITH A CARD LISTING THE VARIOUS OPTIONS REGARDING PUBLICATIONS AND MEMBERSHIP WITH THE REQUEST THAT THE MEMBER CHECK THE PUBLICATIONS AND MEMBERSHIPS DESIRED AND MAIL A PAYMENT FOR SAME TO THE SECRETARY IN ADVANCE OF THE ANNUAL MEETING. THE SPECIAL RATES APPLY ONLY TO ADVANCED SUBSCRIPTIONS. MEMBERS FAILING TO RETURN THE CARD WITH PAYMENT FOR DUES AND SUBSCRIPTIONS BEFORE THE ANNUAL MEETING WOULD LOSE THE DISCOUNT ALLOWED IN THE CLUB RATES.

Advanced information regarding the approximate number of PROCEEDINGS desired will be necessary during the first few years of publication.

Bills for any expenditures made in connection with the duties of their office by the officers of the sections would be presented to the Secretary-Treasurer of the A. S. A. for payment.

IV. HOW WOULD THIS PROPOSED MERGER AFFECT EXISTING ORGANIZATIONS?

1. *American Soil Survey Association.*—This group would unite with the Soils Section of the A. S. A. to form the new American Society of Soil Science, or whatever name it decides to adopt. The various subjects discussed at its annual meeting would continue to be discussed before the appropriate section of the new organization. Papers dealing strictly with soil morphology, classification, and mapping would be presented before Section or Commission V, subjects of interest to both morphologists and chemists would be presented before joint meetings of these two groups. The program of Section V would no longer be crowded by the inclusion of chemistry or physics papers having little or nothing to do with morphology. As a member of the new S. S. S., however, every one would be entitled to join any or all of the six sections or commissions.

By establishing an affiliation with the A. S. A. the overhead costs of running the organization would be reduced. The collection of dues, printing and mailing of programs, etc., would be handled by the office of the Secretary-Treasurer of the A. S. A. The editing of the PROCEEDINGS could probably be done by the Editor of the JOURNAL of the A. S. A. The BULLETIN would be superceded by the PROCEEDINGS of the new Society with all the advantages pointed out above. While the name A. S. S. A. would disappear, the objectives for which it was created will unquestionably be furthered by this union with the other soil scientists of the country.

2. *Soils Section of the A. S. A.*—The existing sections would continue to function much as they have in the past. Closer cooperation with the morphology group would be assured. The formation of the new S. S. S. and the publication of the annual volume of PROCEEDINGS should greatly strengthen the work of this group.

3. *American Society of Agronomy.*—The new organization (S. S. S.) would serve as the Soil Science Division of the A. S. A. No change in the new constitution of the Society seems to be necessitated by the action proposed. The same close affiliation of soils and crops men which has existed in the past is preserved in the present arrangement. The proposed changes will undoubtedly strengthen the Soil Science Division and, as a consequence, the A. S. A.

Active membership in the Agronomy Society would be restricted to those paying $5.00 dues for membership and the JOURNAL. The members of the S. S. S. (all paying the $1.00 membership fee) would be entitled automatically to associate membership in the Society of Agronomy with the privileges specified in the constitution of (1) participating fully in all meetings, and (2) offering papers for publication in the JOURNAL.

To avoid confusion the committee would like to suggest that the TWO SECTIONS OF THE A. S. A. BE KNOWN AS THE CROPS SCIENCE DIVISION AND SOIL SCIENCE DIVISION, respectively. The term section can then be used for the groups within a Division.

4. *The American Section of the International Society of Soil Science.*—As now constituted, the American Section is a skeletal organization for the consideration of matters of interest to the American members. It will not organize programs and hence will not compete in this respect with other organizations. The constitution provides for officers to be elected annually. As there will often be little or no business to transact in off-congress years, it would seem more logical to make the terms of the officers of the American Section correspond to that of the Society as a whole, that is, 5 years or from one congress to the next. This

would mean selecting this fall officers to serve until the fall following the Congress in Germany in 1940.

It was suggested above that dues for all the soils groups be paid to the Secretary-Treasurer of the American Society of Agronomy. This would be but little additional work for his well-organized office and would eliminate the present duplication. In the schedule of dues proposed the rate for those who are members of the I. S. S. S. only would pay the American Section dues of 50c a year plus the amount due the Treasurer of the International Society. Members not wishing to join the American Section could of course send in their dues to Secretary Hissink directly. Members of the S. S. S. having already paid a membership fee would be exempted from this additional fee and would pay merely the amount required by the International Society. (This was reduced to 7.50 Dutch Guilders per year at the Oxford Congress.)

THIS IS A PRELIMINARY REPORT. IT IS SUBJECT TO MODIFICATION BEFORE, AT, AND AFTER THE CHICAGO MEETING IN DECEMBER. IF APPROVED IN PRINCIPLE, A NEW COMMITTEE SHOULD BE APPOINTED TO COMPLETE THE DETAILS.

NEWS ITEMS

ON OCTOBER 9 a special dinner was given by the members of the Agronomy Department and their wives at Iowa State College in honor of Dr. P. E. Brown, who celebrated his fiftieth birthday and who has completed twenty-five years of service in the Department. Dr. W. H. Stevenson, who was head of the Department during 22 years of the time Dr. Brown has been at Iowa State College, acted as toastmaster and paid high tribute to Dr. Brown and the efficient service he has rendered to the institution and to soil science and agronomy. Fifty-two people were in attendance.

DR. L. A. RICHARDS has joined the staff of Iowa State College where he will devote half of his time to the teaching of physics and half to research work in soil physics in the Agronomy Section of the Agricultural Experiment Station. Dr. Richards' research will deal primarily with problems relating to soil moisture and the erosivity of soils.

ROY E. BENNETT has resigned his position as Research Assistant Professor of Soils at Iowa State College to accept a position with the Soil Conservation Service with headquarters at Bethany, Missouri.

DR. W. W. WORZELLA was recently appointed Assistant in Plant Breeding, Purdue University. He will devote his time to research in the fundamental factors affecting the quality and winter hardiness in soft winter wheat.

ALFRED J. ENGLEHORN, Research Assistant Professor of Soils at Iowa State College, has been granted a leave of absence and is serving as Assistant Land Planning Specialist in the Land Planning Division of the Resettlement Administration with headquarters at Ames.

DR. E. R. HENSON, Associate Professor of Farm Crops at Iowa State College, is on leave of absence to assist with the program of the Resettlement Administration in Washington, D. C.

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GREEN PASTURES FOR THE PLANT BREEDER[1]

H. K. HAYES[2]

WHILE I have a broad general interest in many phases of agronomy, my own personal research has dealt chiefly with crop improvement including genetics of crop plants and the production of improved varieties with particular emphasis on disease resistance. I have decided, therefore, to discuss some of the accomplishments in plant breeding during the last 35 years, 26 of which I have spent in this field, and take a brief glimpse into the future.

In recent years some have maintained that one of the causes of over-production has been the development of high yielding varieties. This criticism of the work of plant breeders needs little discussion. The use of efficient varieties is one means of lowering the cost of production and efficiency of production certainly is an economic necessity if agriculture is to advance at the same rate as industry. Several writers have brought out the fact that industry supports a greater body of research in proportion to capital invested than does agriculture. Research that aims at more efficient production in agriculture must continue in the future as in the past.

If you have noted my title, "Green Pastures for the Plant Breeder", you may have concluded that this is only another instance of an agronomist gone wrong. You may have decided that the main theme of this talk would deal with some phase of that elusive game of golf that to some agronomists is an avocation. My own experience, however, leads to the conclusion that few agronomists are physically or temperamentally fitted to make that sort of green pastures more than a mild diversion. I have thought of "Green Pastures" in a symbolic sense. The successful plant breeder or other research worker must enjoy his occupation and to him it must be of outstanding importance. Green pastures for the plant breeder then refer to verdant fields for research and experimentation. In developing this thesis, I shall mention outstanding accomplishments in the field of plant breeding

[1]Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 1391 of the Journal Series, Minnesota Agricultural Experiment Station. Presidential address delivered before the 28th annual meeting of the Society held in Chicago, Ill., December 5, 1935.

[2]Chief of the Division of Agronomy and Plant Genetics.

during the last 25 years, attempt an analysis of the main reasons for the success attained and discuss future possibilities.

The science of genetics as we know it today has been developed mainly during the period from 1900 to the present time. The great changes in plant breeding methods that have occurred during this period have resulted mainly from the application of plant genetic principles to the problems of the breeder. Plant breeding has become a science to the extent that plant genetics and other fundamental researches in plant sciences have been applied to the production of improved varieties. Dr. F. R. Immer tells of a talk with Dr. H. Nilsson-Ehle, the celebrated Swedish plant breeder, in which he asked Dr. Nilsson-Ehle if he thought plant breeding should be classed as a science or an art. The reply of this great leader was, "There is a great deal of art to plant breeding," and then he added emphatically, "*But more science.*"

This is not the time nor place to elucidate the many changes in genetic viewpoint that have occurred during the present century. It seems sufficient to emphasize the present conception that characters are the end result of the interaction of genetic factors and environment, that what is inherited is the manner of reaction under particular conditions and that most normal characters of crop plants are dependent on the interaction of a considerable number of genes. The art and science of plant breeding includes a determination of the most desirable characters of each particular crop after a study of available material including the wild relatives of the crop, the development of improved varieties containing these characters and at the same time discarding or eliminating undesirable characters. In accomplishing this end the plant breeder uses Mendel's Laws as a working method. Accomplishments in breeding disease resistant varieties of spring wheat and improved hybrid strains of corn will be used as illustrations.

BREEDING SPRING WHEAT RESISTANT TO STEM RUST

One of our main cooperative projects at Minnesota since 1915, in which agronomists, plant geneticists, cereal chemists and plant pathologists have cooperated, has been the development of a rust resistant variety of spring wheat of desirable agronomic type and of satisfactory milling and baking quality. This work is carried on thru cooperation between the Minnesota Experiment Station and the U. S. Dept. of Agriculture.

In these studies artificial epiphytotics of stem rust have been developed both under field conditions and in the greenhouse. The rust nursery in the field has consisted of several thousand rows yearly. During the early period of this study resistant vulgare wheats were unknown. Our present nursery has such a preponderance of strains of vulgare wheats highly resistant to stem rust that it is necessary to plant a considerable amount of susceptible host material in order that rust may develop sufficiently in the rust nursery so that a satisfactory spread of the disease may be made possible. The development of rust resistant strains has been accomplished by obtaining resistance from the Emmer group and the combining of this resistance with

desirable agronomic characters of vulgare wheats thru a series of crosses and selections.

While at the present time much remains to be known about various phases of stem rust resistance in wheat, many problems have been solved. Some of the steps that have led to our present position may be mentioned.

1. The mode of inheritance of particular types of reaction to stem rust has been determined both in the greenhouse and field. The most important practical result of these studies is the conclusion that resistance to all forms of stem rust of wheat in the stage from heading to maturity may be dependent upon only a single or few genetic factors.
2. The pathogene causing the disease is composed of numerous forms, called physiologic forms, that can be differentiated by their manner of reaction on a series of wheat varieties and species known as differential hosts, this separation being made primarily on the basis of seedling reaction. Physiological resistance in the seedling stage is of such a nature that a wheat may be immune from one form of rust and susceptible to another. As an illustration, Kanred winter wheat and derivatives are immune from certain forms and highly susceptible to others. This knowledge explained the reason why Kanred winter wheat and derivatives may be highly resistant in one season and highly susceptible in another.
3. A knowledge of the causes of resistance has been of major importance. Thus the resistance of Kanred is physiological and acts only against particular rust forms. A second type of resistance in the field to many forms of rust as the plants approach maturity appears to be simply inherited. The exact cause of this type of resistance is unknown. Some have suggested that morphological and functional causes may be responsible. Others have given evidence indicating that this does not seem to be the explanation. Mature plant resistance is inherited, in some cases, in a simple Mendelian manner, especially where Hope and H44 are used as the resistant parents.
4. It has been learned also that extreme conditions of environment may cause an apparent breaking down of resistance to a particular disease. For example, a plant genotypically resistant to stem rust, if infected with loose smut, may be completely susceptible to rust. This conclusion seems essential in a logical viewpoint of disease resistance in plants. No one expects a potentially high yielding variety will give high yields under unfavorable conditions. Extreme conditions of environment may strongly modify reaction to disease by modifying the character which under normal conditions is responsible for the resistance to that particular disease.

Since 1915 at various times there have been periods when the development of spring wheats, satisfactory in other respects and carrying the desired stem rust resistance, looked to be an impossible task. A new variety named Thatcher, first released in the spring of 1934 and rather widely distributed in Minnesota, withstood the severe

epidemic of 1935 remarkably well when other varieties such as Marquis and Ceres were severely injured. This variety has high yielding ability and appears desirable in milling and baking qualities. There is still room for improvement in several characters. Thatcher, however, appears to be a great step forward.

One of our leading plant breeders, Dr. Gaines of the Washington Agricultural Experiment Station, has made the statement that the study of disease resistance in plants and the development of resistant varieties has been one of the main reasons for the great popular interest in the science of genetics. My own illustration with spring wheat emphasizes the value of cooperation in research, the need of intensive study in order to solve underlying principles thus making possible the solution of complex problems and the development of the desired variety.

BREEDING IMPROVED HYBRIDS WITH CORN

Agronomists rather generally have a knowledge of what has been and is being accomplished with corn by modern methods of breeding. At any rate, hybrid corn is not a novelty today. The change in breeding methods came about by extensive and intensive research in which many members of this society have had a part. I shall not attempt an analysis of all major steps leading to our present position.

Comprehensive studies were undertaken about 1906 at the Connecticut Station by Dr. E. M. East and at Cold Spring Harbor by Dr. G. H. Shull. I had the privilege of starting my own work on corn improvement under Dr. East's direction in 1909. I was impressed with a statement of Dr. East's about this time that he started studies of self fertilization and crossing in corn to learn the physiology of inheritance in corn with the belief that this knowledge was a necessity in order to develop a logical plan of corn improvement. During my early studies a leading botanist asked me if we thought it would be possible to continue self fertilization, as he believed inbred lines of corn would run out eventually. The Mendelian explanation of hybrid vigor, and the results obtained from studies of self and cross-fertilization with many species, have been essential to an understanding of the physiology of inheritance with cross pollinated plants.

Jones' suggestion in 1917 for the use of double crosses did away with one of the early obstacles in the way of producing hybrid seed commercially. The studies of many investigators furnished a basis for a partial standardization of corn breeding technic. The work includes self fertilization and selection to obtain desirable inbred lines, top crosses to estimate the better combining lines, the test of single, three-way and double crosses of the most desirable lines, the selection and commercial propagation of the better lines and hybrids and the production of hybrid seed by commercial producers.

One of our large canners of sweet corn in Minnesota, the Minnesota Valley Canning Co., undertook several years ago the improvement of sweet corn by modern plant breeding methods under our general supervision. They expect next year to use hybrid seed for the greater part of their entire pack. Investigators in Iowa have adopted the policy of introducing hybrids only when they are 25 per cent superior

to normal corn. Other states have reported marked increases in yield, ability to withstand lodging and in disease resistance of hybrids over normal varieties. The time is rapidly approaching when all progressive corn growers will use hybrid seed.

These results with hybrid corn have been brought about by intensive and extensive studies in corn improvement, carried out at many experiment stations and by private breeders. Many problems in corn breeding remain to be solved and new technics will be developed without doubt. The most important problem is to develop improved inbred lines. The reason for the remarkable combining ability of certain lines should be determined. There is need with corn as with other crops for more knowledge of the relative desirability of differential characters and the differences should be made known in terms of morphology, taxonomy, ecology, cytology, physiology, and pathology as well as in genetics.

These studies should answer such questions as the value of high or low leaf area in corn for different ecological regions, the relative importance of various types of root development, the causes of ability to withstand various types of lodging and of drought resistance. Questions of this nature are essential to the breeder and are of equal interest to other plant science workers.

It has been my purpose to give a glimpse of several plant breeding accomplishments and to emphasize the many questions that remain unsolved with crop plants such as corn and wheat that have received most extensive study. With these crops a good start has been made. The number of research problems yet unsolved furnishes future "green pastures" with crop plants for students of plant sciences.

IMPROVEMENT OF GRASSES

With many crop plants much less has been accomplished in crop improvement than with corn and wheat and with some crop plants, particularly the grasses, studies of improvement have not progressed very far. As one investigator stated the problem, the grass plants are in much the same condition as would result if all wheat varieties were mixed together and grown as a single crop without varietal separation. We should not overlook the fact that some countries of the world have made a good start in grass improvement, notably Wales, Sweden, and Canada. Our own country lags far behind altho there is much evidence of renewed interest in grasses and forage crops. A greater acreage in these classes of crops is recommended by agronomists and others for the future for many regions of United States in connection with the agricultural planning studies that have been made this last summer. Efficiency of production demands efficient varieties.

At present methods of breeding grasses and forage crops have not been standardized. The necessary information for such standardization is not available and certainly all grasses can not be handled by the same breeding method. There is a serious lack of such essential information as mode of pollination, extent of self sterility, and relative desirability in grasses of self fertility or sterility. It is evident that many grasses are mixtures of self fertile and self sterile lines. With

red clover, for example, where formerly it was considered that cross fertilization was necessary to seed production, it is now known that highly self fertile lines can be selected. By genetic methods it should be easy to combine self fertility with other characters if that is desirable.

With timothy, some breeders in America have concluded that self fertilization and selection was a logical method of improvement. Several foreign workers state that timothy is highly self sterile and that self fertile and vital lines are so infrequent that self fertilization and selection are not logical methods of improvement.

At a conference on alfalfa improvement in Washington, there was a wide divergence of views regarding the extent to which self fertilization could be used as a logical tool in alfalfa improvement. The probable effects of self fertilization and selection with each of the grasses and forage crops should be made known.

All that was emphasized regarding the value of an intensive knowledge of differential characters with corn and wheat is of equal importance in grass and forage crop improvement. The returns from such intensive studies of grass and forage crop improvement would, I am sure, yield a handsome dividend, based on the cost of the research. Several trained investigators in nearly every state of our Union could find pleasant and profitable employment in grass and forage crop improvement. It is our privilege as agronomists to emphasize the importance of fundamental research as a means of developing efficiency in agriculture.

PROBLEMS IN THE BREEDING OF MILLET (*SETARIA ITALICA* (L.) BEAUV.)[1]

H. W. Li, C. J. Meng, and T. N. Liu[2]

MILLET is one of the few main food crops in North China. Its importance is only second to that of wheat, the leading crop of the region. The grain is used for human consumption as well as for feed for livestock. Millet straw furnishes the main forage for the livestock of the district. In the past, some selection work has been done in several experiment stations of North China; but so far as the writers are aware, no varieties are ready to distribute to farmers. Moreover, all the breeding work that has been carried out thus far follows methods used with small grains. It is urgent and necessary, therefore, to study some of the problems that one may encounter in millet breeding work. The senior author (1)[3] published a preliminary note on this work in 1934; but since then, additional work has been carried out and the results are now reported in this paper.

ANTHESIS

Some knowledge of the blooming habits of a species is necessary before artificial hybridization can be carried out successfully. The detailed description of the opening of the millet flower has been reported (1); however, a brief summary of the process is given here.

MANNER OF BLOOMING

Each spikelet of millet has two flowers, the lower one sterile, the upper one with both stamens and pistil. Under normal conditions, blooming starts about 5 days after the head emerges from the boot. The flowers open gradually. As the glumes begin to spread, the anthers and pistil push their way out (Fig. 1), although sometimes they come out simultaneously. As a general rule, the anthers begin to dehisce after they are fully extruded. This is of particular interest in connection with the technic of hybridization as it will be described later. After dehiscence, the flower begins to close up, leaving only the shrivelled anthers and the tip of the stigma outside. The average time required for the opening and closing of the flower is 70 minutes (average of five varieties).

The order of blooming of the spikelets in the head is very regular, usually starting from the top of the head and proceeding toward the base. For the side branches, the order is the same as for the whole head. It usually requires from 12 to 15 days for the whole head to finish blooming, although of course, this will vary with the environment and the variety concerned.

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[1]Contribution from the College of Agriculture, Honan University, Kaifeng, Honan, China. Received for publication July 2, 1935.

[2]Professor and Associates in Plant Breeding, respectively. The authors are deeply indebted to Dr. H. H. Love of Cornell University for many helpful criticisms and suggestions regarding this paper.

[3]Figures in parenthesis refer to "Literature Cited", p. 970.

TIME OF DAY OF BLOOMING

Rangaswami Ayyangar, *et al.* (2) reported that there is a definite periodicity in the opening of the flowers during the 24 hours, with maxima between 10 p. m. and midnight and between 6 a. m. and 8 a. m. In the hot weather the two periods are nearly equal in intensity, but in cold weather, the second period is only half the intensity of the first.

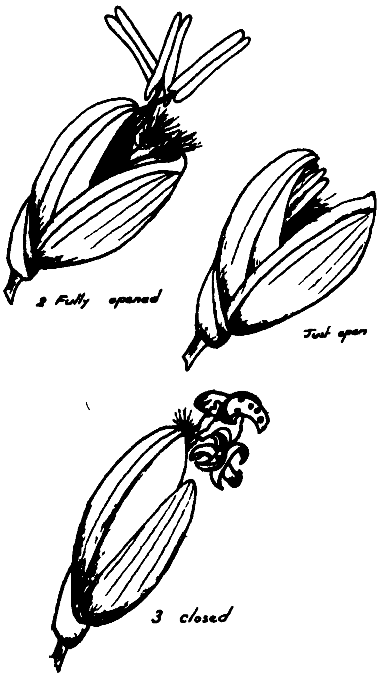

FIG. 1.—Three stages in the blooming of the millet spikelet.

A graphical representation of the hourly blooming record for a 24-hour period in percentage of total blooms for 1933 and 1934 is presented in Fig. 2. It should be noted that the varieties under observation were different for these two years. In 1933, only a single head from a farmer's variety was used; while in 1934, three heads from a selected strain (No. 48) were under observation. These were grown in pots that were placed in a small courtyard bounded on all sides by walls. In 1933, however, the observation was taken under field conditions and 2 weeks later than the observations made in 1934. Consequently, in 1933, the weather was growing much colder with a corresponding change in humidity. Furthermore, in 1934, we had the hottest summer on record for many years, and the observations were carried out in the midst of a hot spell, July 21 to August 2.

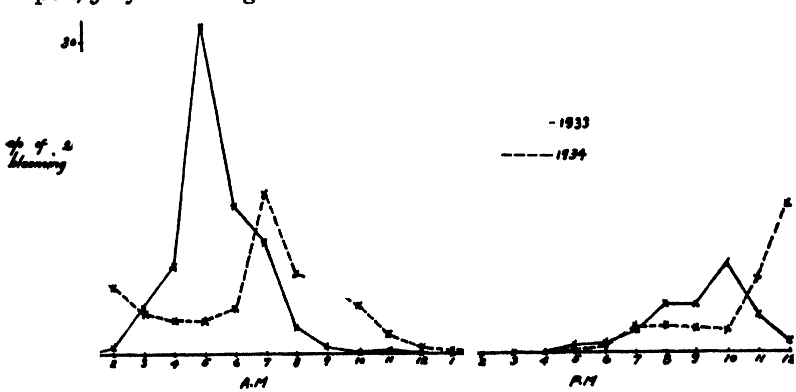

FIG. 2.—Hourly blooming record of millet, Kaifeng, China, 1933 and 1934.

In general, the two curves as shown in Fig. 2 are more or less similar to each other. There are two maxima for both curves. In 1933, the peak for the first period was almost three times as high as for the second and occurred between 4 and 7 a. m. The second period took place between 9 and 11 p. m. In 1934, both periods were almost equal in intensity, the first occurring between 6 and 8 a. m. and the second near midnight. Both periods in 1934 seem to have shifted to the right of those for 1933. This change can be explained by the difference in weather conditions under which the observations were made, as we shall see later that blooming is correlated negatively with temperature and positively with relative humidity. At any rate, our findings seem to agree closely with those obtained in India (2). There is practically no blooming between noon and 6 o'clock in the afternoon, when the temperature is relatively high and when the relative humidity is low.

INFLUENCE OF ENVIRONMENT

Since there are three variables involved in measuring the effect of environment on blooming, *viz.*, temperature, relative humidity, and light, a carefully controlled experiment would require the use of fine apparatus and technic to keep one variable under observation and the other two relatively constant. Unfortunately, our laboratory was not well enough equipped to do this. Nevertheless, we made hourly records of the number of blooms per hour. It was noted that there are always two maxima for the number of blooms in each day, one occurring about midnight and another about 7 o'clock in the morning. Both of these periods occur while the temperature is relatively low (around 75° F) and the relative humidity high. Conversely, when there is no blooming taking place, the temperature is high and the relative humidity low.

Calculating the correlation coefficient between the number of blooms and temperature, we find that $r = -0.1658$, $\eta = 0.1948$, and $\eta^2 - r^2 = 0.010457 \pm 0.00807$. It is apparent that r does not differ significantly from linearity. This correlation coefficient of -0.1658 for $n = 286$ is significant, since from Wallace and Snedecor (3), where $n = 300$ for a 5% level of significance $r = .113$ and for a 1% level of significance $r = .148$. On the other hand, the correlation coefficient between number of blooms and relative humidity is positive, r being 0.1774, $\eta = 0.2217$, and $\eta^2 - r^2 = 0.01768 \pm 0.01042$. Again r in this case does not differ from linearity. (The calculation used for r and η follows the method described by Hayes and Garber, 4). The correlation is again significant for the same level of significance as above. Thus, in general, we may conclude that the number of blooms is positively correlated with relative humidity and negatively correlated with temperature. However, this is inadequate to explain the observation for July 25, when there was practically no blooming at all, despite the fact that it rained the entire day with high relative humidity and relatively constant temperature (around 75° F). It seems that other factors must enter in, but lacking carefully controlled experiments, no further explanation can be made.

In order to observe the effect of light on blooming, one plant was placed in the same courtyard as described above, while another plant was moved into the house where it received only diffused light. Observations were started on July 26, 5 days after the other experiment had commenced. While no records were taken inside of the house, it is reasonable to expect that temperature, humidity, and light were all subject to change. The plant outside the house had two maximum periods of bloom, as can be seen by Fig. 3. The second period was almost 4 times as high as the first one, a difference that cannot be explained at this time. The two periods for the plant inside of the house, however, are about equal in intensity and occurred identically at the same time of day as in the plant outside of the house. Again,

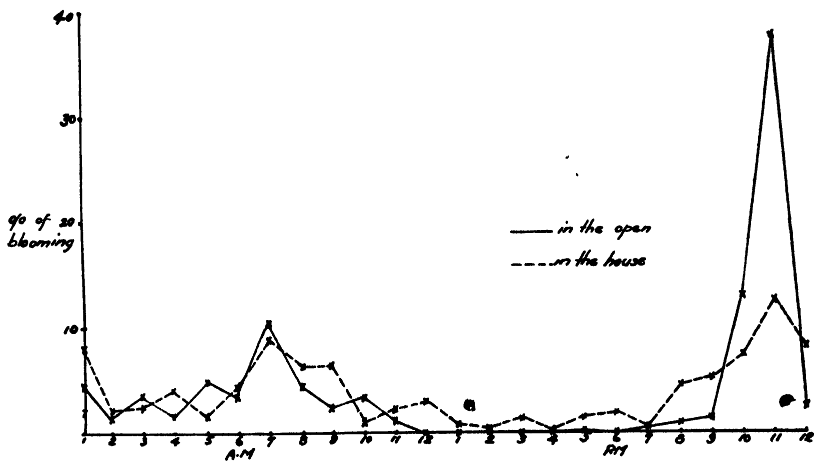

FIG. 3.—Hourly blooming record of millet indoors and in the open.

blooming occurred at almost every hour of the day, even in the afternoon when generally there is no blooming at all. For the lack of control of the other two variables, it is hard to give credit for this change to the effect of light alone.

NATURAL CROSSING

In observation made on the anthesis of millet, it was found that the anthers usually dehisce after their full extrusion from the spikelet. Thus, it is obvious that there must be some natural crossing taking place in millet. Li (1) found the percentage of natural crossing to be 5.60 ± 2.10% in a total of 117,627 kernels at a distance of 1 foot, using non-waxy kernels found among waxy seeds as a criterion. Takahashi and Hoshino (5) found the percentage of natural crossing to be 0.59 as determined by the offspring with colored stems and leaf sheaths in the noncolored strains, but in different strains it varied from 0.09 to 1.09%. In a series of experiments with mixed sowings of colored and noncolored strains, these workers obtained up to 2.26% natural crossing. It seems, therefore, that our figure is a little too

high, due possibly to faulty classification of the waxy and non-waxy kernels.

In order to check this point, 50 heads selected at random from the remnants of the previous experiment were planted each in a different row. At flowering time, pollen grains were gathered from each plant, stained with iodine solution, and examined under the microscope. In the case of waxy plants, the pollen grains stained yellow, while in hybrid plants obtained from natural crossing both yellow and red grains occurred in about equal numbers. This tedious work was discontinued when it was found that the hybrid plant could be picked out by macroscopic examination. The waxy strain used in this experiment was red seeded, with relatively short bristles. The non-waxy strain, on the other hand, had pale yellow seeds and much longer bristles. The hybrid invariably had long bristles. By separating the long-bristled heads from the short-bristled ones, we found that the former totaled 108 out of 1,416 plants. The percentage of natural crossing, therefore, was 7.63, a relatively close check on the previous work.

If this were true for conditions prevailing in Kaifeng, China, to what then could the differences observed by Takahashi and Hoshino (5) in Manchuria and Korea be attributed? This might be explained on two grounds. First, Kaifeng is a semi-desert region with relatively dry atmosphere as compared with that of Manchuria and Korea. Under this condition, the pollen grains can be blown from the place of liberation to the stigma of another plant much more easily. Second, the short-bristled waxy strain used in our experiment might favor the catching of foreign pollen by the exposed and unprotected stigma more readily than a strain with long bristles. Experiments using other strains of millet to determine this point are underway and the results will be reported in a later paper.

ARTIFICIAL HYBRIDIZATION

EMASCULATION

For the sake of carrying on genetical and breeding work with millet, a technic for artificial hybridization had to be developed. Owing to the minuteness of the spikelets of millet (about 1 mm in length), emasculation is very difficult. In fact, we tried repeatedly but failed each time. Fortunately, from the study of anthesis and from observations at other times, it was found that the anthers, as a general rule, shed their pollen outside of the glumes. This opened a way for artificial hybridization. In order to avoid stray pollen, hybridization should be done indoors or in the greenhouse. If it has to be done in the field, it is better to choose a quiet day.

After due protection with glassine bags for both parents, hybridization can be carried out when some of the spikelets from the parents are opening. With the help of a magnifying glass, examine the spikelet just opened. If the anthers are still intact after their full extrusion, pull them off immediately with a fine pair of forceps. Pollination can then be done either by applying pollen to the stigma from anthers of the male parent that are about to shed their pollen, or else by

collecting the pollen grains by simply tapping the glassine bag that protects the male parent and applying this pollen to the stigma. Both methods seem to be equally successful. Pollination can be done immediately after emasculation or a day or two later. Preferably, emasculation and pollination of millet should be carried out early in the morning (around 6 o'clock).

BULK EMASCULATION

When many seeds are wanted from the same cross, especially for back crosses in genetical study, the method described above will not suffice. Hence, the bulk emasculation of flowers was tried out in 1933 and again in 1934. The method used was similar to that described by Stephens (6). A water container was made so that a thermometer could be inserted from the top and two millet heads to be treated could be inserted simultaneously from the ends. Treatments were carried out when there were some flowers opening on the head. During treatment, warm water at the right temperature was put into the container and the millet heads soaked in it. Invariably after the treatment, the temperature was 1° C lower than at the start of the experiment. After the treatment, the treated head was put together with the head to be used as the male parent and both heads covered with a glassine bag. Table 1 shows the results obtained.

TABLE 1.—*Results obtained in a mass emasculation experiment with millet.*

Temperature at start of experiment, ° C	Duration of soaking, min.	Estimated set of seed, %
46°	10	95
47°	15	60
47°	15	40
48°	10	40
48°	10	80
48°	20	10
48°	20	0
48.5°	10	20
48.5°	20	0
49°	10	40
49°	10	2
49°	10	5
49°	10	Few
49°	15	5
49°	20	Few
49.5°	15	50
50°	10	Few
50°	10	0
50°	20	0
51°	5	Few
52°	10	0

From Table 1 it will be seen that when the treatment temperature was beyond 50° C practically no seeds were set, even for short periods of treatment. Also, when the temperature was 48° or 49° C and applied for a longer duration, say at 20 minutes, this again was too severe.

The female parent used in this experiment had green-colored seedlings, and the male parent red seedlings, consequently the progeny should have had red seedlings. Tests of the progenies from the treated heads gave only a negligible number of red seedlings, but this was not sufficient to testify to the success of the treatment because when the pollen grains were killed at a given temperature and time, the ovules were likewise killed. Further experiment will be necessary to draw definite conclusion regarding this point.

CYTOLOGICAL STUDIES

Very little is known about the cytology of millet, hence in 1934, we made some preliminary studies. For the root tips, a chromic, acetic, and formalin solution was used in the following proportions:

Solution A		Solution B	
Chromic acid	3 grams	Formalin	90 cc
Glacial acetic acid	21 cc	Distilled water	210 cc
Distilled water	276 cc		

FIG. 4.—Metaphase plate of somatic mitosis of root tip of millet, showing 18 chromosomes. X 4,000.

Equal parts of both solutions were mixed just before fixation. Paraffin sections were cut 10 microns thick. Newton's iodine gentian violet stain was used. For *Setaria italica*, selection No. 48, Hungarian millet, and one farmer's variety were examined. The common foxtail grass of Kaifeng, known locally as cow's grass, *S. viridis*, was examined also. All have 18 chromosomes as their somatic number (Fig. 4).

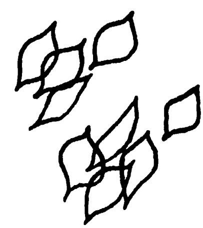

FIG. 5.—Metaphase plate of meiotic mitosis of millet, showing 9 pairs of chromosomes. X 4,000.

Among the nine pairs of chromosomes of *Setaria*, two seem to be longer in length, having submedium constrictions. The other seven shorter pairs are about equal in length and seem to have submedium constriction, except one which is constricted in the middle. However, the morphology of the chromosomes must be verified later.

For microsporogenesis, iron-aceto-carmine was used. Fig. 5 shows the first metaphase of *meiotic* mitosis having nine pairs of chromosomes. All other features of *meiosis* in the materials examined were normal. We may conclude from these results, therefore, that the chromosome number of *Setaria italica* and *S. viridis* is nine.

SUMMARY

1. There are two maximum periods of blooming in millet, one between 4 and 7 a. m. and another between 9 p. m. and midnight. In 1933, when the temperature was cooler, the first maximum was three times as high as the second. In 1934, when the temperature was higher, both periods were of about the same intensity. There was practically no blooming between noon and 6 p. m.

2. The rate of blooming was negatively correlated with temperature and positively correlated with humidity.

3. The percentage of natural crossing was found to be 5.60 ± 2.10 in 1933 and 7.63 in 1934, using the same material in both years but applying different criteria.

4. A method of artificial hybridization is described.

5. The somatic number of chromosomes of *Setaria italica* and *S. viridis* was found to be 18, and their haploid number 9.

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THE BACKCROSS METHOD IN PLANT BREEDING[1]

Fred N. Briggs[2]

As early as 1922 Harlan and Pope[3] pointed out the usefulness of the backcross method in plant breeding, especially its utility in the transfer of specific characters from one variety to another. Later, the author[4] discussed its value in breeding disease-resistant varieties of cereals with special reference to work in developing varieties of wheat resistant to bunt, *Tilletia tritici*. There still seems to be some misunderstanding about the value of this method, due, it is believed, to a lack of appreciation of the fundamental principles involved. It seems appropriate, therefore, to describe how the backcross operates to bring about the desired results.

That homozygosity is increased at a rapid rate when plants are self-fertilized is well known to plant breeders. The proportion of homozygous individuals may be calculated from the following equation:

$$\text{Proportion of homozygosity} = \left(\frac{2^m - 1}{2^m}\right)^n$$

where m is the number of generations of selfing and n is the number of heterozygous genes. It is apparent that as m increases the proportion of homozygous individuals will become greater. With 10 pairs of factors over 85% of the population will be homozygous at the end of six generations. The number of homozygous genotypes equals 2^n where n is the number of pairs of factors. With the 10 pairs above the homozygous plants would be equally divided among 1,024 genotypes, therefore, either parent will occur once in 1,024 times among these homozygous individuals.

If a heterozygous population is continuously backcrossed to one of the homozygous parents, homozygosity is attained at the same rate as if self-fertilization is employed. Therefore, in the above equation m becomes the number of back-crosses used. For instance, with 10 pairs of factors, if the population is backcrossed six times, 85% of the population will be homozygous, but instead of there being 1,024 different homozygous genotypes, all the homozygous individuals will be of a single genotype, namely, that of the backcross or recurrent parent.

A simple cross between a white-kerneled club wheat and a red-kerneled lax wheat, in which the characters named depend on single factors, may be used to illustrate the difference between self-fertilization and backcrossing. The percentage of homozygosity and the percentage of the entire population which will be made up of parental combinations indicated may be seen in Table 1.

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[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication October 19, 1935.

[2]Assistant Professor.

[3]Harlan, H. V., and Pope, M. N. The use and value of back-crosses in small grain breeding. Jour. Heredity, 13:319. 1922.

[4]Briggs, Fred N. Breeding wheats resistant to bunt by the back-cross method. Jour. Amer. Soc. Agron., 22:239–244. 1930.

TABLE 1.—*The percentage of homozygous individuals and parent combinations expected in five generations of self-fertilization as compared with five backcrosses to each parent in a cross of white-kernel club (parent I) x red-kernel lax (parent II) wheat cross.*

Generations	Self-fertilized		Backcrossed to P. I		Backcrossed to P. II	
	% homo	% homo white club or red lax	% homo	% homo white club	% homo	% homo red lax
1	25.00	6.25	25.00	25.00	25.00	25.00
2	56.25	14.06	56.25	56.25	56.25	56.25
3	76.56	19.14	76.56	76.56	76.56	76.56
4	87.79	21.97	87.89	87.89	87.89	87.89
5	93.84	23.46	93.84	93.84	93.84	93.84

You will note that the percentage of homozygous individuals is exactly the same in each of five backcrosses as it is in each of five generations of selfing. Where selfing is used, the homozygous individuals are equally divided among four genotypes, therefore, only one-fourth of these will have the same combination of the characters under consideration as either parent. On the other hand, where backcrossing is used, all the individuals will have the same combination as the recurrent parent.

It seems probable that the yield, quality, and adaptation of the best varieties of wheat, for example, in any locality may be due to the accumulation in these varieties of a fairly large number of favorable genes affecting these characters. Furthermore, it seems probable that many of these genes may exert a relatively small effect, so that they come under the category of modifying factors. Consequently, their presence in hybrid progenies is difficult to detect with the result that the selection of plants with such favorable combinations is extremely uncertain. If we assume only one heterozygous pair of genes for each chromosome pair in a wheat cross, there would be 2^{21}, or 2,097,152 different homozygous genotypes in subsequent generations, or the better parent type would occur only once in over 2,000,000 times. It will be apparent that the desirable characters of the more desirable parent may be preserved automatically by using it as the recurrent parent. Any factor or factors desired from the other parent will have to be maintained by selection.

The ease with which the backcross method can be used depends on a number of considerations. The simplest case is where the character to be transferred depends on a single gene about which the genetics is fully known. The frequency at which successive backcrosses may be made will depend on the ease with which the character to be transferred can be followed in hybrid populations. In transferring resistance to bunt from Martin to commercial varieties of wheat, the author has thought it desirable to get the resistant factor into the homozygous condition between each two or three backcrosses. In other cases it may be feasible to backcross every generation. At the end of the first backcross it may be possible to practice some selection to advantage, but after the third or fourth backcross the material is all

so nearly like the recurrent parent that any selection of characters other than the one being transferred is not practical.

Even in many crosses where the main consideration is the increase of some more or less intangible character, such as quality or adaptation, a judicious amount of backcrossing might be employed to advantage. In any cross where one parent is more desirable commercially than the other, the F_1 may be backcrossed to the better parent without the likelihood of losing any genotypes, provided a reasonable number of backcrossed seed are made. However, there will be considerable shift in the progeny toward the recurrent parent. In the F_2 of a single cross either parent will appear once in 4^n plants, where n again is the number of pairs of heterozygous genes. However, at the end of the first backcross the recurrent parent will occur once in 2^n number of plants. Again assuming 21 pairs of factors the recurrent parent will occur once in 2,097,152 individuals where the F_1 is backcrossed, but the same parent will occur only once in 4,398,046,-511,104 individuals in an F_2 from a single cross. Therefore, the recurrent parent combination would occur 2,097,152 times as often in the backcross as in the straight cross.

It seems to the author that the immediate need for such field crops as wheat is more dependable production. The plant breeder can accomplish much in this direction by adding disease and insect resistance to the best commercial varieties now available. The backcross method of breeding is admirably suited for such a program. Should one wish to add resistance to bunt and to stem rust to a commercial variety, for example, a separate backcross program should be set up for each disease and the end-products crossed together. If one has already produced a bunt-resistant strain, then it should be used as the recurrent parent because the resistance to bunt will then be taken care of automatically. Resistance to other diseases or additional factors for resistance to the same disease may be added from time to time as suitable parental material becomes available.

UNIFORMITY TRIALS WITH COTTON[1]

FU SIAO[2]

SINCE the publication of Mercer and Hall's paper in 1911, many studies have been made to determine desirable methods of conducting field trials. The primary purpose has been to learn the most efficient methods of making comparative tests. For certain groups of crops the general methods suggested by Love and Craig (7)[3] have been used extensively.

Only a few studies have been made with cotton. Engledow and Yule (2) suggested 1/80-acre plats with a few replications. Bailey and Trought (1), in 1928, recommended that the beds should be in long strips (up to 16 times as long as wide) and that where possible, each strip should be 1/5 feddan in area (1 feddan = 1.038 acres). They recommended 10 replications, and where sufficient land or seed was not available, the number of replications might be made up by dividing the strip into sections. Because of great seasonal variations, they stated that the trial should be carried out over a period of at least 3 years. Ligon (5) suggested the use of single row plats not longer than 100 feet, with three replications.

The results of these investigators differ widely and no generalization can be made. A blank test was carried out by the writer over a period of 3 years, beginning in 1930, at Yuyao, Chekiang, China, in the hope of throwing some light on desirable methods of field experimentation with cotton. This paper summarizes the results of that test.

MATERIALS AND METHODS

Two hundred rows of cotton each 24 feet long, and spaced 1 foot apart were planted in a single series in 1930 and in 1931. Seed was sown in drills and the seedlings were thinned finally to 30 plants per row, more or less evenly distributed. In 1932, 22 ridged beds each 192 feet long were planted with the same variety of cotton. The beds were 4.5 feet in width and occupied by three rows of cotton. Each bed was cut into 12 sections and the crop from each section harvested separately. Owing to the existence of border effect the plats on the border were discarded. As a result only 200 plats arranged in a 20x10 block were used in the analysis.

Varying numbers of single rows were combined to form plats of different width for the study of the most efficient size of plat. In each case 25 varieties were assumed in the test except for the three-row plats in 1932 where only 20 varieties were assumed. In 1932 the size of plat was increased in both directions by extending the length of the plat or by expanding the width of the plat. Because of the

[1]Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. This paper is a summary of a thesis submitted to the Graduate School of the University of Minnesota as a partial fulfillment of the requirements for the degree of master of science, June 1934. Received for publication October 31, 1935.

[2]Graduate Student. The writer wishes to express his appreciation to Dr. H. K. Hayes, Chief of the Division of Agronomy and Plant Genetics, for his helpful direction throughout the analysis of the data and in the preparation of the manuscript.

[3]Reference by number is to "Literature Cited", p. 979.

difference in basic size of plat and in arrangement of the plats, the results for 1932 were treated separately from 1930 and 1931. The method of "Analysis of Variance" suggested by Fisher (3) was used in the analysis of the results. The efficiency of different sizes of plats was obtained by dividing the calculated variance of a plat of basic size by the product of the variance of larger plats and the number of basic plats making up the larger plat. Harris' (4) method of estimating soil heterogeneity was applied in 1932 to trace the direction of the soil variation.

Randomized blocks, Latin squares, and systematic arrangement of plats were compared by finding the distribution of the differences between the assumed varieties.

The standard error for systematic arrangement was based on the check plats only which were assumed to occur every fifth plat. The theoretical yield of the test plats was obtained by the grading method suggested by Love (6). Then the difference between the yield of the assumed varieties and the theoretical yield was calculated and compared with the standard error of a mean difference. A standard error calculated from an analysis of variance was used to obtain a standard error of a mean difference between the assumed varieties in randomized blocks and in Latin squares. The distribution of differences from these three methods of arrangement was tested by the X^2 test against the theoretical random distribution.

EXPERIMENTAL RESULTS

SIZE OF PLAT

The data in Table 1 show a gradual reduction of experimental error as the plat increased in size. The coefficient of variability in 1930 dropped from 14.05% to 9.86% as the plat increased from a single row to eight rows in width. In 1931 the change in the coefficient of variability for the same increase in size of plat was from 22.34% to 12.75%, or a reduction of about 44% of the total. The difference in the amount of reduction of error between these two years might be attributed to the wide differences in yield. It is generally true that the experimental error is larger in an unfavorable season and larger plats are more advantageous under these conditions.

TABLE 1.—*Standard errors and coefficients of variability for different sizes of plats in 1930 and 1931.*

Size of plat	1930		1931	
	S. E.	C. V.	S. E.	C. V.
One-row	18.54	14.05	13.80	22.34
Two-row	19.21	14.54	11.65	18.85
Three-row	16.51	12.69	11.10	17.90
Four-row	16.57	12.53	9.99	16.17
Eight-row	13.03	9.86	7.88	12.75

Increasing the size of plat decreases the variability of the experiment by increasing the precision of a single plat yield. On the other hand, there is an increase in the variability within the block through expanding the area included in the block. There are two opposing tendencies that affect the experimental error as the plat changes in size, the final result being due to a balance between these two ten-

dencies. The slow rate of reduction in experimental error through increase in size of plat and, in some exceptional cases, the greater variability for larger plats, may be explained by increase in variation within the block as the plat increases in size.

The efficiency of different sizes of plats was calculated on the single-row plat basis in order to compare the relative efficiency of plats of varying size for a given area of land. The results are summarized in Table 2. Taking the single-row plat as a basis in 1930, the two-row plat was only 46.58% as efficient; that is to say, a test in two-row plats was only 46.58% as accurate as a test in single-row plats replicated once. The two-row plats in 1931 were only 70.16% as efficient as the single-row plat replicated once. For these two years there was a gradual reduction in efficiency as the plat increased in size. In other words, the larger the plat the lower the efficiency. The lower efficiency was entirely due to the existence of soil heterogeneity. Had the soil variation been uniform over the entire field, the different sizes of plat would be equal in efficiency.

TABLE 2.—*The relative efficiency of different size of plat in 1930 and 1931.*

Size of plat	1930		1931	
	Variance	Efficiency	Variance	Efficiency
One-row	343.92	100.00	190.39	100.00
Two-row	369.16	46.58	135.68	70.16
Three-row	272.46	42.08	123.14	51.54
Four-row	274.47	31.32	99.81	47.69
Eight-row	169.69	25.33	62.06	38.35

Since the plats were arranged in a 20 x 10 block in 1932, there was an opportunity to increase plat size in both directions. In the following discussion increasing the length of plat will be referred to as "by length" and expanding the width of the plat as "by width." The former extension would include plats on the same bed, while the latter combines the plats on adjacent beds. Results are given in Table 3.

A two-unit plat had a much smaller error than a single-unit plat no matter in which way the plat was expanded. The coefficient of variability was reduced from 10.13% for a one-unit plat to 7.14% for a two-unit plat by width and to 8.06% for a two-unit plat by length. The efficiency of the two-unit plat by width was 100.86 and that of two-unit plat by length was 79.19. The high efficiency for the two-unit plat by width was not expected. A correlation coefficient of .061 ± .058 revealed no association between adjacent plats; consequently, the two-unit plat by width should be equal in effi-

TABLE 3.—*Variance and efficiency of different size of plats in 1932.*

Size of plat	Variance	C. V.	Efficiency
One-unit	464.92	10.13	100.00
Two-unit (by width)	230.47	7.14	100.86
Two-unit (by length)	293.81	8.06	79.12

ciency to a one-unit plat. The loose association between adjacent plats was due probably to the fact that these plats were on two ridged beds separated by a furrow.

The results indicated the wide plat was more desirable than a long narrow plat. To be more exact, the most suitable shape of the plat was determined by the degree of association of adjacent plats. The plat extended in the direction of least association or greatest variation is the most desirable.

REPLICATION

The number of replications needed to attain a certain degree of accuracy may be found by dividing the standard error of a unit plat by the desired error and squaring the quotient. The theoretical number of replications to reduce the standard error to 5% for different sizes of plats is given in Table 4. For single-row plats only 7.9 replications were needed in 1930, while 20 replications were required to attain the same degree of accuracy in 1931. For an eight-row plat 3.9 replications were needed in 1930 and 6.5 replications in 1931. This fact shows that in an unfavorable season the larger plat was more advantageous than under more favorable conditions. Because of wide difference in variability, no definite number of replications can be recommended.

TABLE 4.—*Theoretical number of replications needed to reduce the standard error to 5%.*

Size of plat	1930	1931
One-row	7.9	20.0
Two-row	8.5	14.2
Three-row	6.4	12.8
Four-row	6.3	10.5
Eight-row	3.9	6.5

Twenty varieties were assumed to be tested in 200 rows in 1930 and 1931 and in 200 plats in 1932. This gave opportunity to study either five or ten replications for randomized blocks and four or eight replications for systematic arrangement for the year 1930 and 1931, and to study the arrangement in randomized blocks and Latin squares in 1932. Theoretically, the mean differences between the assumed varieties should be zero, and therefore, the differences should be distributed normally around this mean. Because of the similar nature of the data from 1930 and 1931, the distribution of the differences between the assumed varieties were entered in the same frequency table and tested by the X^2 test for goodness of fit. Table 5 shows the distribution of differences where five replications were used in randomized blocks. A X^2 value of 3.04 was obtained, which, according to Elderton's table (8) for $n' = 6$, gave a P value of .69.

For ten replications in randomized blocks, the calculated X^2 value was 8.21 with a P value of .09. The result indicated that the departure of the observed distribution from the theoretical was non-significant.

TABLE 5.—*X^2 test for goodness of fit between the observed and expected distribution of differences in randomized blocks between the hypothetical varieties with five replications for 1930 and 1931 combined.*

Class limit in S. E.	Observed	Calculated	(O–C)	$(O-C)^2/C$
±. 00–± .49	288	291	3	.03
± .50–± .99	224	228	4	.07
±1.00–±1.49	143	140	3	.06
±1.50–±1.99	65	67	2	.06
±2.00–±2.49	26	25	1	.04
±2.50–±2.99	14	9	5	2.78
				$X^2 = 3.04$

In systematic arrangement one-fifth of the total area was occupied by the assumed check variety. Consequently, only four or eight replications were possible where five or ten replication could be accommodated for randomized blocks. The differences between the observed yield of the plat and the theoretical yield were calculated by the grading method from the adjacent check plats, and then were entered in the distribution table in the intervals of standard error of the mean difference. A X^2 test was applied to test the goodness of fit between the observed and calculated distribution. With four replications X^2 equaled 4.33, with $n' = 4$, giving a P value of .23 or a chance of 23 out of 100 in favor of the occurrence of such a deviation due to chance alone. The X^2 value for eight replications was below 1 and gives a P value above .80.

The same method was followed in studying replication in 1932. The distribution of the differences between hypothetical varieties is given in Table 6. The last class included all the frequencies above 2.0 x S. E. as the individuals above that class were too few to be treated as a single class. In the Latin squares the class 1.50 to 1.99 included all differences above 1.50. In randomized blocks the calculated X^2 value of 5.87 with an $n' = 4$ gave a P value of .21. In Latin squares X^2 being 4.34 with $n' = 4$ led to a P value of .23. The distribution of the differences between the hypothetical varieties were according to expectation.

TABLE 6.—*Frequency distribution of difference between hypothetical varieties arranged in Latin squares and randomized blocks, 1932 data.*

Ranges in S. E.	Randomized blocks			Latin squares		
	Expected	Observed	Diff.	Expected	Observed	Diff.
± .00–± .49	73	63	10	36	35	1
± .50–± .99	57	58	1	28	21	7
±1.00–±1.49	35	47	12	17	23	6
±1.50–±1.99	17	15	2	9	11	2
±2.00 and above	8	7	1	—	—	–

The randomized blocks because of the local control had an experimental error lower than with systematic arrangement and in turn Latin squares gave a lower error than randomized blocks through the control of error in both directions. In 1930, for ten replications

in randomized blocks, the standard error was 5.91 and for eight replications in systematic arrangement the standard error was 8.20. In 1931 the standard errors were 4.39 and 5.15 for randomized blocks and systematic arrangement, respectively. In 1932 in comparing the randomized blocks and Latin squares the variances were 46.49 and 34.42, respectively.

SUMMARY

1. Increase in size of plat was accompanied by reduction in experimental error, but larger plats were lower in efficiency than the smaller plats. This indicated that increase in number of replications was much more efficient than increasing the size of plat.
2. The shape of the plat was determined by the direction of soil variation. The increase in size of plat in the direction of least association was most efficient.
3. Because of high seasonal variation no definite number of replications could be recommended. Each of the three methods of replication, *viz.*, systematic arrangement, randomized blocks, and Latin squares, were studied and differences between hypothetical varieties compared with calculated standard errors. By means of X^2 for goodness of fit each gave good agreement with mathematical expectation.

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STATISTICAL ANALYSES APPLIED TO RESEARCH IN WEED ERADICATION

Frank F. Lynes[1]

THE following article is a preliminary report of investigations being conducted in Otero County, Colo. It is believed to be the first report of the use of variance analysis in weed eradication research. The value of the data given is limited in as much as it involves only a 1-year test, but the method employed is believed to be a progressive step in scientific weed research.

For this particular test the randomized-block method was selected because of its adaptability to tests which are planned for the future. This method, developed by Fisher (3),[2] is particularly adapted to research work conducted in connection with the Otero County weed eradication program.

For this test a *Convolvulus arvensis* (wild morning glory or field bindweed) area was selected on the George Seamans' farm, located 3 miles east and 1½ miles south of Rocky Ford, Colo. The experiment consisted of 15 treatments and 5 replications with plats 1 square rod in size. The plat arrangement and treatment were as follows:

Plat arrangement and treatment number.

Block I	Plat	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
	Treatment	15	2	13	10	3	9	11	8	4	12	6	7	5	1	14
Block II	Plat	4	9	14	19	24	29	34	39	44	49	54	59	64	69	74
	Treatment	14	7	9	2	13	10	5	11	8	15	4	6	12	3	1
Block III	Plat	3	8	13	18	23	28	33	38	43	48	53	58	63	68	73
	Treatment	5	4	13	8	11	7	1	14	10	9	12	3	2	15	6
Block IV	Plat	2	7	12	17	22	27	32	37	42	47	52	57	62	67	72
	Treatment	3	15	12	1	6	9	8	7	5	14	10	2	4	13	11
Block V	Plat	1	6	11	16	21	26	31	36	41	46	51	56	61	66	71
	Treatment	15	11	8	14	13	2	1	5	10	9	6	4	12	7	3

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The writer wishes to express his appreciation to G. W. Deming, Assistant Agronomist, U. S. Dept. Agriculture, for his helpful criticism in the preparation of this article. Received for publication October 3, 1935.

[2]Figures in parenthesis refer to "Literature Cited", p. 987.

Treatments.

Treatment No.	Treatment	Plat No.
1	1 bbl. beet molasses	17, 31, 33, 70, 74
2	¾ bbl. beet molasses	10, 19, 26, 57, 63
3	½ bbl. beet molasses	2, 25, 58, 69, 71
4	¼ bbl. beet molasses	8, 45, 54, 56, 62
5	3 lbs. Atlacide dissolved in 1 gal. water	3, 34, 36, 42, 65
6	3 lbs. sodium chlorate dissolved in 1 gal. water	22, 51, 55, 59, 73
7	3⅛ gal. Crafts acid arsenical	9, 28, 37, 60, 66
8	Same as No. 7 plus 3⅛ gal. water next a.m.	11, 18, 32, 40, 44
9	Same as No. 8 plus straw before applying water	14, 27, 30, 46, 48
10	2% solution of acid arsenical stock solution	20, 29, 41, 43, 52
11	Acid injury plus treatment No. 7	6, 23, 35, 39, 72
12	Acid injury plus treatment No. 8	12, 50, 53, 61, 64
13	Check (no treatment)	13, 15, 21, 24, 67
14	Cleaned off all vegetation then applied No. 5	4, 16, 38, 47, 75
15	Cleaned off all vegetation then applied No. 6	1, 5, 7, 49, 68

The toxic effect of Steffins House discard beet molasses on succulent weeds has been brought to the attention of the writer and instances of its use in the eradication of bindweed have been reported. Beet molasses was included in this test to gain more definite information as to its possible value as a weed eradicator. The molasses was furnished by the Rocky Ford factory of the American Crystal Sugar Company. Their analysis of the molasses is as follows:

Approximate analysis:

Sucrose	55%	Dry substance	80.17%
Rafinose	2½%	Total nitrogen	1.68%
Water	20%	Nitrate nitrogen	0.52%
Organic matter	22½%	Carbonate ash	13.05%

Analysis of ash:

		Combined:	
SiO_2	0.04%	KCL	3.50%
Fe_2O_3 and Al_2O_3	0.03%	K_2SO_4	3.39%
CaO	0.11%	K_2CO_3	2.23%
MgO	0.03%	$CaCO_3$	0.19%
K_2O	5.57%	$MgCO_3$	0.07%
Na_2O	2.15%	Na_2CO_3	3.67%
SO_3	1.55%	SiO_2	0.04%
Cl	1.66%	Fe_2O_3 and Al_2O_3	0.03%
CO_2	2.35%		
	13.49%		13.12%
O–CL equiv	0.38%		
	13.11%		

The molasses was applied by buckets with perforated bottoms in order to obtain a uniform coverage of each plat with the desired amount of molasses. For some time there has been a controversy between weed workers as to the comparative value of chlorate treatments. Four of these treatments were incorporated in this test in order to obtain data as a basis for recommendations for the use of chlorates in the weed program.

Crafts acid arsenical spray was incorporated in the test because at present it is the leading spray employed in the Otero County weed

eradication program. It has been suggested that an application of water the following morning will considerably increase the effectiveness of this spray and this was incorporated in the test to obtain an indication of its value. It has also been suggested that covering the area with straw and then applying the water would maintain a high humidity and thus considerably increase the effectiveness of the spray. This was also incorporated to obtain an indication of its value. The use of jars or cans placed some distance apart and filled with a 2% solution of the acid arsenical stock solution into which the tops of the adjacent plants are immersed has also been suggested and was used in this test.

Crafts (1, 4) has suggested that any agent which kills the leaves but not the stems will cause the production of a secondary tissue which is more efficient for the rapid conduction of water than the normal stem. A concentration experiment for leaf injury to produce secondary growth was carried on at the Rocky Ford substation of the Colorado Agricultural Experiment Station. All plats were 1/3 square rod in size.

Various dilutions of commercial sulfuric acid (66° Baume) were applied on August 7, 1934 at the rate of 1 gallon per plat. The results are given in Table 1.

TABLE 1.—*Effect of sulfuric acid on field bindweed.*

Plat No.	Amount of acid per gal.	Normality	Percentage (vol.)	Observations, Aug. 20, 1934
1	1 qt.	0.5	25.00	Burnt off all vegetation
2	1 pt.	0.25	12.50	Burnt off all vegetation
3	½ pt.	0.125	6.25	Burnt off all vegetation
4	¼ pt.	0.0625	3.125	Killed all vegetation
5	⅛ pt.	0.03125	1.56	Few live stems
6	4 tbs.	0.025	1.25	Few live stems
7	3 tbs.	0.01875	0.94	Many live stems
8	2 tbs.	0.0125	0.62	All stems alive and parts of leaves alive
9	1 tbs.	0.00625	0.31	No appreciable injury

From the data it may be assumed that 1 gallon of a 0.5% solution by volume of commercial sulfuric acid per 1/3 square rod, or 3 gallons per square rod, would produce the desired injury.

The following method was used in preparing, and applying the acid arsenical treatments (2). A stock solution is prepared as follows:

	As_2O_3	NaOH	H_2O (cold)
By weight	4 parts	1 part	3 parts
Mixture	44.464 lbs.	11.116 lbs.	4 gal.

This makes 5½ gallons of stock solution containing 50% As_2O_3 by weight. The As_2O_3 and NaOH are mixed thoroughly in the dry state in an iron container and the cold water added slowly. The mixture should be worked in the open to avoid the fumes.

The spray solution is then prepared by adding 1 gallon of the stock solution and 5 gallons of commercial sulfuric acid (66° Baume) to 200 gallons of water.

Prof. Bruce J. Thornton, Associate Botanist, Colorado State College, gives the following directions for applying the spray: The plants must be mature; the soil not excessively moist; applications made between 6:00 and 12:00 p.m.; employ No. 4 size nozzle at 125 lbs. pressure, applying 500 to 600 gallons per acre; plants should be thoroughly wet and an excess of spray should be built up on the foliage if possible; a thorough application of water the next morning considerably increases the effectiveness.

The chlorate treatments were also applied according to the recommendation of Professor Thornton, as follows: Three pounds of the material dissolved in 1 gallon of water and applied at 125 lbs. pressure using No. 1 size nozzle. This test was conducted in the spare time of the writer and for that reason the application of the various treatments extended over a longer period of time than is desirable.

A schedule of the dates of application of the treatments is given below.

1934 data

Date of Treatment	Remarks
Aug. 15 to 25	Stand counts
Aug. 15 and 16	Applied beet molasses
Aug. 25	Placed cans 3 feet apart for 2% stock solution for treatment No. 10
Aug. 27	Applied Atlacide, treatment No. 5
	Applied 2% solution of acid arsenical stock solution at 6:00–7:00 p.m.
	Cleaned off all vegetation for Atlacide treatment No. 14
Aug. 28	Applied Crafts acid arsenical at 10:30 p.m. to 3:00 a.m.
Aug. 29	Cleaned off all vegetation for sodium chlorate treatment No. 15
	Applied straw and water for treatment No. 9
	Applied water for treatment No. 8
Sept. 12	Applied acid injury treatment for treatment Nos. 11 and 12 in the afternoon
Sept. 15	Applied sodium chlorate for treatment Nos. 6 and 15 in the afternoon
Sept. 20	Applied acid arsenical treatment for treatment Nos. 11 and 12 at 10:00–11:00 a.m.

1935 data

July 13	Stand counts

Soil samples were taken on the area on September 5, 1934, to ascertain the moisture content and the results presented in Table 2.

TABLE 2.—*Soil sample data.*

Plat No.	Depth, inches	Weights, grams					Moisture %
		Wet	Oven dry	Oven dry jar	Oven dry soil	Total moisture	
3	0–18	448.8	438.5	303.4	135.1	10.3	7.62
	18–60	624.5	596.0	284.0	312.0	28.5	9.13
28	0–18	511.2	490.2	297.6	192.6	21.0	10.90
	18–60	592.0	567.2	298.4	268.8	24.8	9.23
73	0–18	423.9	408.7	301.4	107.3	15.2	14.17
	18–60	443.7	420.3	283.5	136.8	23.4	17.11

Weather data covering the winter season preceeding the test and the period during which the test was conducted are presented in Table 3.

TABLE 3.—*Weather data.**

Date	Temperature		Mean temperature		Total precipitation, in.
	Max.	Min.	Max.	Min.	
Oct. 1933	80°	26°	72°	35°	0
Nov. 1933	70°	12°	57°	24°	0 13
Dec. 1933	69°	12°	51°	24°	0.87
Jan. 1934	64°	9°	50°	19°	0.05
Feb. 1934	70°	7°	47°	23°	1 03
Mar. 1934	75°	4°	57°	26°	0.27
Apr. 1934	83°	24°	67°	38°	0.84
May 1934	94°	34°	81°	51°	0.74
June 1934	100°	46°	91°	54°	0.37
July 1934	106°	55°	99°	62°	1.19
Aug. 1934	102°	41°	94°	60°	1.80
Sept. 1934	92°	29°	81°	46°	0.88
Oct. 1934	94°	25°	77°	38°	0
Nov. 1934	80°	8°	61°	25°	0.15
Dec. 1934	64°	3°	50°	17°	0.05
Jan. 1935	68°	—12°	54°	17°	0
Feb. 1935	75°	0°	53°	19°	0
Mar. 1935	81°	18°	63°	30°	0.37
Apr. 1935	82°	20°	66°	36°	0.48
May 1935	88°	26°	68°	44°	2.45
June 1935	98°	42°	87°	53°	1.01
July 1935	101°	54°	96°	59°	0

*Data furnished by Herman Fauber in charge of the Rocky Ford Sub-station.

In order to have an accurate criterion to rely upon for a comparison of these widely different treatments, actual stand counts were made on the plats and are presented in Table 4, together with the calculated percentages of return growth. A square meter quadrat, as used in range work, was employed in obtaining the counts. The quadrat was placed at random approximately in the center of each plat and the number of shoots at the ground line determined. The reason for placing the quadrat near the center of the plat was to avoid possible border effects from adjacant treatments. A statistical analysis of the data is presented in Table 5.

According to this analysis, treatments Nos. 5, 6, 7, 9, 14, and 15 are significantly better than the check and there are no significant differences between these treatments. Further, this analysis indicates that:

1. The chemicals now in use give a significant kill.
2. The chlorates may be applied as a soil treatment or as a foliage spray without any significant differences in the kill.
3. There is no significant difference between Altacide and sodium chlorate.
4. Crafts acid arsenical is as effective as the chlorates.
5. The modifications of Crafts spray are not significantly different from his spray.

TABLE 4.—*Stand counts of field bindweed.*

Plat No.	1934 stand	1935 stand	% return	Plat No.	1934 stand	1935 stand	% return	Plat No.	1934 stand	1935 stand	% return
1	101	8	7.92	27	374	165	44.12	53	374	118	31.55
2	309	105	33.98	28	403	136	33.75	54	525	335	63.81
3	180	100	55.56	29	382	264	69.11	55	516	75	14.53
4	400	58	14.50	30	484	203	41.94	56	399	72	18.05
5	407	64	15.72	31	397	116	29.22	57	436	160	36.70
6	168	118	70.24	32	452	112	24.78	58	429	249	58.04
7	293	27	9.22	33	613	90	14.68	59	456	65	14.25
8	412	190	46.12	34	413	122	29.54	60	316	212	67.09
9	330	115	34.85	35	393	431	109.67	61	331	98	29.61
10	431	150	34.80	36	593	130	21.92	62	504	303	60.12
11	190	75	39.47	37	484	80	16.53	63	388	248	63.92
12	342	189	55.26	38	416	120	28.85	64	372	141	37.90
13	518	195	37.64	39	602	282	46.84	65	419	67	15.99
14	389	109	28.02	40	607	270	44.48	66	462	69	14.94
15	415	246	59.28	41	388	130	33.51	67	362	290	80.11
16	165	85	51.52	42	674	148	21.96	68	444	20	45.05
17	495	133	26.87	43	555	304	54.77	69	489	545	111.45
18	283	139	49.12	44	472	122	25.85	70	447	345	77.18
19	490	80	16.33	45	564	456	80.85	71	401	505	125.94
20	365	310	84.93	46	325	63	19.38	72	139	146	105.04
21	274	181	66.06	47	511	110	21.53	73	225	128	56.89
22	510	117	22.94	48	513	58	11.31	74	364	166	45.60
23	473	212	44.82	49	545	98	17.98	75	316	132	41.77
24	375	235	62.67	50	543	344	63.35	76	120	0	0
25	456	216	47.37	51	341	40	11.73	—	—	—	—
26	222	114	51.35	52	490	236	48.16	—	—	—	—

TABLE 5.—*Analysis of data arranged according to treatments.*

No.	Treatment	Block I	Block II	Block III	Block IV	Block V	Total	Average
1	1 bbl. beet molasses	77.18	45.60	14.68	26.87	29.22	193.55	38.71
2	3/4 bbl. beet molasses	34.80	16.33	63.92	36.70	51.35	203.10	40.62
3	1/2 bbl. beet molasses	47.37	111.45	58.04	33.98	125.94	376.78	75.36
4	1/4 bbl. beet molasses	80.85	63.81	46.12	60.12	18.05	268.95	53.79
5	3 lbs. Atlacide dissolved in 1 gal. water	15.99	29.54	55.56	21.96	21.92	144.97	28.99
6	3 lbs. sodium chlorate dissolved in 1 gal. water	14.53	14.25	56.89	22.94	11.73	120.34	24.07
7	3 1/8 gal. Crafts acid arsenical spray	67.09	34.85	33.75	16.53	14.94	167.16	33.43
8	Same as 7 plus 3 1/8 gal. water next a.m.	44.48	25.85	49.12	24.78	39.47	183.70	36.74
9	Same as 8 plus straw before applying water	41.94	28.02	11.31	44.12	19.38	144.77	28.95
10	2% solution acid arsenical stock solution	84.93	69.11	54.77	48.16	33.51	290.48	58.10
11	Acid injury plus 7	109.67	46.84	44.82	105.04	70.24	376.61	75.32
12	Acid injury plus 8	63.35	37.90	31.55	55.26	29.61	217.67	43.53
13	Check (no treatment)	59.28	62.67	37.64	80.11	66.06	305.76	61.15
14	Cleaned off all vegetation then applied 5	41.77	14.50	28.85	21.53	51.52	158.17	31.63
15	Cleaned off all vegetation then applied 6	15.72	17.98	45.05	9.22	7.92	95.89	19.18
	Totals	798.95	618.70	632.07	607.32	590.86	3247.90	

Σd^2 plats 189465.5230—140651.3921 =48814.1309
Σd^2 blocks 2138576.3994÷15 = 142571.7599—140651.3921 = 1920.3678
Σd^2 treatments 812448.7784÷ 5 = 162489.7557—140651.3921 = 21838.3636
Subtraction factor $\frac{(3247.90)^2}{75}$ = 140651.3921

Analysis of variance:

	Sum of Squares	D.F.	Mean Square	1/2 Log e	
Blocks	1920.3678	4			5% point <.3691
Treatments	21838.3636	14	1559.88311	3.67619	1% point <.5224
Error	25055.3995	56	447.41785	3.05175	Z value .6244
Total	48814.1309	74			

Level of significance:

S. E. of plat $\sqrt{447.41785}$ = 21.1522540
S. E. of a mean 21.1522540÷$\sqrt{5}$ = 9.4595755
S. E. of a difference 9.4595755 x $\sqrt{2}$ = 13.3778603
Difference required for significance 2 x 13.3778603 = 26.7557206 or 26.76

6. Beet molasses is not effective in the concentrations used in this experiment.

In spite of the ineffectiveness of beet molasses in this experiment it is effective in greater concentrations as indicated by the results obtained on plat 76. This plat was located on an adjacent area and

was 1 square meter in size. One-half barrel of beet molasses was applied to this plat. Although this concentration was effective, at the present cost of $2.00 a barrel this treatment would not be practical.

SUMMARY

The value of the data presented here is limited inasmuch as they cover only a 1-year test. However, the methods employed should offer a means of accurately comparing methods of weed eradication. It is the earnest hope of the writer that this report will inspire other workers to utilize variance analysis in their experimental work on weed eradication. The use of stand counts offers an accurate means of comparing the percentage kill.

The analysis indicates that the chemicals now in use give a significant kill and that there is no significant difference between the chlorates and the acid arsenical. Since the arsenical spray is cheaper and does not have a residual effect on the soil, making it possible to grow a crop on the land each year to help defray the cost of application, it would seem to be more economical for use in Otero County, Colo., in the eradication of *Convolvulus arvensis* (field bindweed) than are the chlorates.

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THE ASSIMILATION OF PHOSPHORUS BY *ASPERGILLUS NIGER* AND *CUNNINGHAMELLA* SP.[1]

F. B. SMITH, P. E. BROWN, AND H. C. MILLAR[2]

NUMEROUS biological methods for determining the available phosphorus in soils have been proposed. These methods are all based upon the assumptions that the growth of certain soil micro-organisms is proportional to the amount of available phosphorus present in the soil and that all the phosphorus available to the micro-organisms would be available to crop plants.

In an investigation of the effect of phosphorus on nitrogen fixation by Azotobacter, Thompson and Smith (4)[3] obtained results which indicated that large amounts of phosphorus were not assimilated by the Azotobacter and hence were not necessary for their growth.

Koszelecki (1) grew *Aspergillus niger* in a medium containing 10% glucose, 1% asparagin, 0.5% $MgSO_4$, 0.1% KCl, 0.001% $ZnSO_4$, and phosphorus supplied in 100, 50, or 25 grams of soil. The mycelium was weighed after 6 days and analyzed for phosphorus. The amount of phosphorus assimilated was found to be 1:200 of the weight of the mycelium.

Simakova and Bovschik (3) determined the amount of phosphorus assimilated by *Aspergillus niger* after 6 days. They found that the amount of phosphorus in the mycelium was directly proportional to the amount of phosphorus in the medium.

Thompson, Smith, and Brown (5) found that *Aspergillus minutus* did not produce as much mycelium in a dextrose solution culture medium as *Aspergillus luchuensis*. However, *Aspergillus minutus* contained a larger percentage of phosphorus and assimilated more phosphorus than *Aspergillus luchuensis*.

The results reported in this paper were obtained in a further study of the activities of molds in certain Iowa soils, determining their phosphorus assimilating power.

EXPERIMENTAL PROCEDURE

Aspergillus niger and *Cunninghamella* sp. were selected for the study since the growth of these two molds has been used as a measure of available phosphorus in soils. A medium containing 1% dextrose, 0.5% peptone, 0.05% $MgSO_4 \cdot 7H_2O$, 0.1% $NaNO_3$, and 0.1% K_2SO_4, and referred to as dextrose medium A, was used for comparison with the medium recommended by Niklas, *et al.* (2). A medium similar to dextrose medium A, except that it contained 10% dextrose, was also used and is referred to as dextrose medium B. Varying amounts of the different phosphates were added to the phosphorus-free media as shown in the different experiments.

The media were placed in wide-mouth extraction flasks for inoculation and growth of the molds. In all cases, except where otherwise stated, 60 cc of the

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[2]Associate Professor, Professor, and Fellow, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 1000.

medium were placed in 150-cc flasks and 1 cc suspensions of young spores were used for inoculation. The spore suspensions were prepared by inoculating 50 cc of the medium containing 200 p.p.m. of phosphorus in extraction flasks and incubating 6 to 10 days at 35°C. The excess medium was drained from the flask and the mycelium rinsed twice with small amounts of distilled water. A small amount of distilled water was added, and the flask stoppered and shaken vigorously to dislodge the spores. The contents of the flask were then emptied on a screen placed over a funnel and the spores washed into a 500-cc Erlenmeyer flask with distilled water. The spore suspension was made up to 200 cc.

Four flasks in each treatment were inoculated, except in one case where six relpicate cultures were inoculated. The cultures were incubated 5 to 6 days at 35°C. The mycelium was removed at the end of the incubation period, washed, dried, and weighed according to the procedure outlined by Niklas, *et al.* (2).

RESULTS

1. WEIGHT AND PHOSPHORUS CONTENT OF MYCELIUM GROWN ON DIFFERENT MEDIA

Phosphorus additions were made as $CaH_4(PO_4)_2.H_2O$ in the amounts of 0, 0.246, 2.46, 24.6, 246, 492, 738, 984, 1,230, and 1,476 p.p.m. to the Niklas medium and to dextrose medium A. Fifty cc of the media were placed in 250-cc extraction flasks. Six flasks were prepared for each concentration of phosphorus. There were two series of flasks for each medium, the one being inoculated with *Aspergillus niger* and the other with *Cunninghamella* sp. The cultures were incubated 5 days. The phosphorus content of the mycelium was determined by the official method. The results obtained are presented in Tables 1 and 2 and in Figs. 1, 2, and 3.

Cunninghamella sp did not make any appreciable growth in the Niklas medium. No mycelium was produced by *Aspergillus niger* in the phosphorus-free Niklas medium. The weight of mycelium in the replicate cultures varied considerably, especially at the lower concentrations of phosphorus. However, the mean weights of mycelium of the six cultures varied significantly and were almost proportional to the amount of phosphorus in the medium. This relation between the weight of mycelium and the concentration of phosphorus in the medium did not hold above about 500 p.p.m. of phosphorus, although the percentage of phosphorus in the mycelium continued to increase.

The curve for the *Aspergillus niger* in the Niklas medium (Fig. 1) up to about 500 p.p.m. of phosphorus is a typical exponential curve as evidenced in the straight line obtained when the logarithm of the weight of mycelium is plotted against the logarithm of the concentration of phosphorus in the mycelium (Fig. 2).

There was considerable growth of both molds in dextrose medium A, to which no phosphorus had been added. Apparently the peptone added in this medium contained some phosphorus available to these molds. The weight of mycelium was almost proportional to the amount of phosphorus in the medium at the lower concentrations of phosphorus, but an increase in the concentration of phosphorus did not bring about a corresponding increase in the weight of mycelium at the higher concentrations of phosphorus. In dextrose medium B,

TABLE 1.—*Weight and phosphorus content of mycelium of A niger and Cunninghamella sp grown in various media.*

Culture No	Mgm phosphorus in 100 cc of medium																			
	0		0 0123		0 1230		1 230		12 30		24 6		36 9		49 2		61.5		73.8	
	A*	B*	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
	A niger in Niklas' Medium																			
1	0	0	24	0 3638	72	0 3908	402	0 6737	1161	3 045	1414	5 174	1388	5 309	1322	5 174	1340	8 188	1480	20 12
2	0	0	33	0 3301	68	0 3099	355	0 6602	1135	2 937	1425	4 648	1330	5 282	1332	5 498	1359	9 029	1334	11 09
3	0	0	26	0 2707	57	0 4160	383	0 5928	1209	3 012	1420	4 635	1372	5 371	1355	5 484	1346	7 666	1373	12 98
4	0	0	41	0 3908	79	0 4042	272	0 6330	1198	2 964	1433	5 012	1389	5 552	1361	6 333	1345	8 409	1338	—
5	0	0	35	0 2916	56	0 1348	411	0 7264	1143	3 045	1414	4 298	1393	5 659	1375	6 576	1342	8 100	1340	—
6	0	0	31	0 3368	41	0 4582	339	0 6871	1155	2 924	1416	4 730	1393	5 552	1364	5 012	1343	—	1337	—
Average	0	0	33 3	0 3306	62 2	0 3523	360 6	0 6622	1166 8	2 9878	1420 3	4 7495	1377 5	5 4541	1351 6	5 7128	1345 8	8 2784	1367	14 73
	A niger in Dextrose Medium A																			
1	159	0 1212	169	0 1074	189	0 2289	134	0 9025	156	1 536	238	2 412	240	2 553	212	2 614	258	4 231	241	3 726
2	151	0 0939	174	0 1210	193	0 2424	162	0 9968	157	1 644	226	2 492	230	2 830	217	2 422	221	3 112	195	3 274
3	152	0 0939	165	0 1074	185	0 2289	158	0 9768	161	1 657	242	3 227	226	2 654	206	3 112	228	3 450	225	2 802
4	153	0 1074	172	0 1206	189	0 2289	150	0 9968	171	1 832	243	2 480	242	2 897	225	2 776	257	4 918	248	4 002
5	—	—	165	0 1074	190	0 2289	148	0 9431	171	1 832	267	2 715	220	2 546	221	2 735	226	3 638	231	3 194
6	—	—	176	0 1074	196	0 2560	161	0 9780	159	1 684	240	2 156	219	2 480	254	3 610	213	3 938	196	2 856
Average	153 7	0 1041	170 1	0 1118	190 3	0 2356	152 1	0 9656	162 5	1 697	242 6	2 280	229 5	2 615	222 5	2 878	233 8	3 881	222 6	3 309
	Cunninghamella sp in Dextrose Medium A																			
1	97	0 2964	113	0 3098	97	0 3368	102	0 9698	160	3 610	211	5 127	222	5 228	234	6 023	221	6 454	219	6 980
2	98	0 2964	99	0 3098	102	0 3503	142	0 9698	162	4 689	219	5 160	229	5 511	227	6 252	237	6 238	216	6 684
3	105	0 2964	88	0 3098	92	0 3634	86	0 9296	123	1 940	235	5 080	240	5 646	216	5 820	223	6 050	227	6 600
4	91	0 2964	95	0 3098	91	0 3770	109	0 8890	165	4 230	219	4 833	222	5 652	223	5 870	216	6 320	215	6 171
5	—	—	89	0 3098	100	0 3970	113	0 8890	153	6 638	231	5 160	218	5 713	224	5 734	217	5 619	221	6 172
6	—	—	109	0 3098	96	0 3970	99	0 8890	167	3 604	221	4 952	217	5 592	224	5 895	203	5 821	223	6 333
Average	97 7	0 2964	98 8	0 3098	98	0 3686	108 5	0 9227	155	4 118	222 6	5 052	224 6	5 557	224 6	5 932	219 5	6 084	220 1	6 490

* A columns are weight of mycelium "B columns, weight of phosphorus in mycelium

similar to dextrose medium A except that it contained 10% of dextrose, the weight of mycelium was materially increased at the higher concentrations of phosphorus (Table 2).

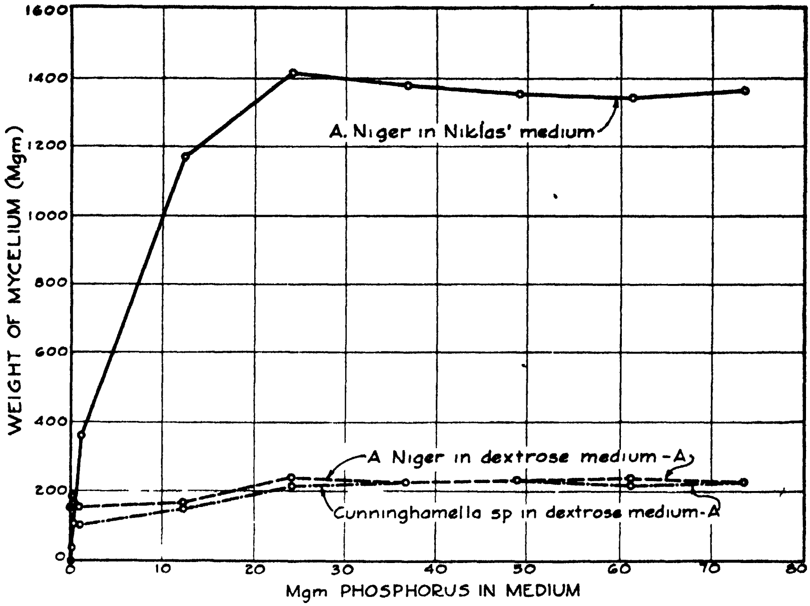

FIG. 1.—The influence of phosphorus on the weight of mycelium of *Aspergillus niger* and *Cunninghamella* sp. in different media.

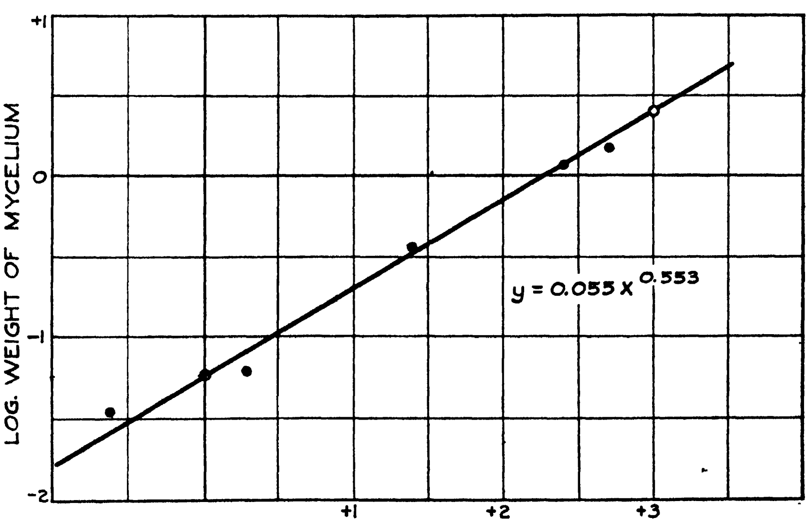

FIG. 2.—Relation of weight of *Aspergillus niger* mycelium to concentration of phosphorus in Niklas medium.

TABLE 2.—*Weight and phosphorus content of A. niger and Cunninghamella mycelium grown in dextrose medium B.*

Culture No.	Mgm phosphorus in medium							
	A. niger				*Cunninghamella* sp.			
	12.3		24.6		12.3		24.6	
	A*	B*	A	B	A	B	A	B
1..........	746	—	860	6.373	532	3.934	561	8.448
2..........	705	3.557	842	5.659	669	3.800	571	7.600
3..........	801	3.826	790	6.063	—		—	
Average	750.6	3.691	830.6	6.031	600.5	3.867	566.0	8.024

*"A" columns are, weight of mycelium; "B" columns, weight of phosphorus in mycelium.

Analysis of the data shows that the amount of phosphorus in the *Aspergillus niger* mycelium was not significantly correlated with the

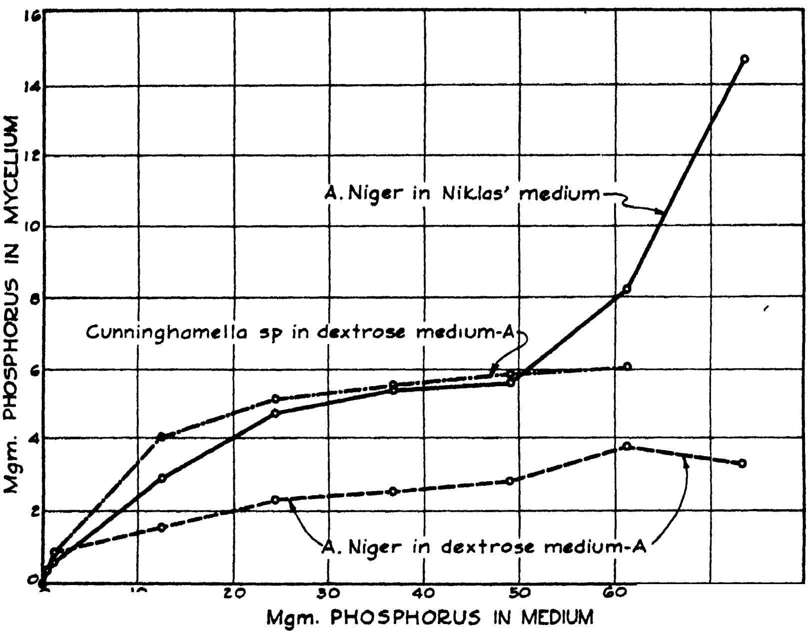

FIG. 3.—The assimilation of phosphorus by *Aspergillus niger* and *Cunninghamella* sp.

weight of mycelium in the replicate cultures, but the correlation was highly significant between the means of the six cultures at the different concentrations of phosphorus.

2. RELATION OF WEIGHT OF *Aspergillus niger* MYCELIUM TO CONCENTRATION OF PHOSPHORUS IN MEDIUM

The data obtained in the preceding experiment indicated that the weight of mycelium was a function of the concentration of phosphorus in the medium at concentrations of phosphorus below about 500 p.p.m. Since soils containing more than 500 p. p. m. of available phosphorus would be unlikely to show a need for phosphate fertilizers, the weight of *Aspergillus niger* mycelium might indicate the needs of the soil for phosphorus if the relation between the weight of mycelium and phosphorus content were better known.

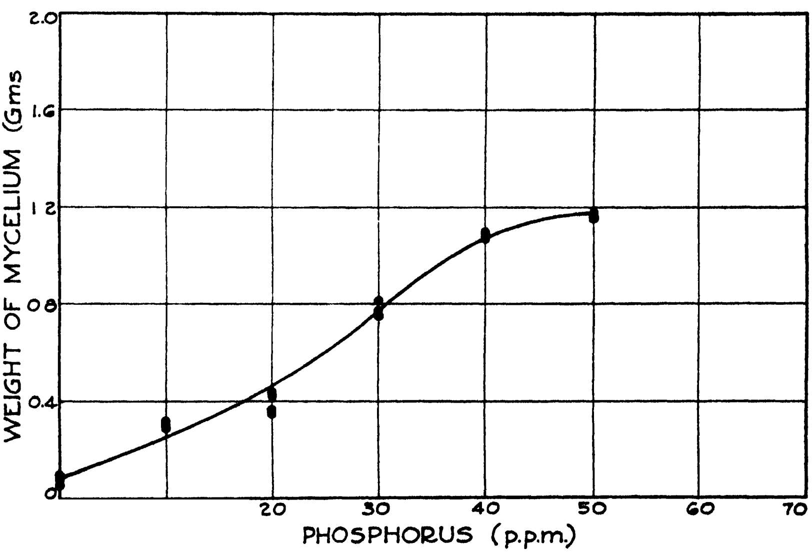

FIG. 4.—Relation of weight of *Aspergillus niger* mycelium to concentration of phosphorus in the medium.

In order to get more information about this relationship, *Aspergillus niger* was grown in varying concentrations of phosphorus and the weight of mycelium determined.

The concentration of phosphorus was varied at intervals of 10 p.p.m. up to 50 p.p.m. Four flasks of the Niklas medium were prepared for each concentration of phosphorus and inoculated with *Aspergillus niger* spores. After incubation the mycelium was dried and weighed. The results obtained are presented in Fig. 4.

The data show that as the concentration of phosphorus increased the weight of mycelium also increased, but the relationship was not the same as in the first experiment. There was a considerable growth of the mold in the phosphorus-free medium, and at 10 p.p.m. of phosphorus the weight of mycelium was 320 mgm. The two experiments were conducted in the same manner, except that the inoculum for the second experiment was from a different batch of spores. The age of the spores used for inoculation was about the same in both

cases, but there was no check on the approximate number of spores carried in the 1 cc used for inoculation in the two experiments.

3. RELATION BETWEEN SIZE OF INOCULUM TO WEIGHT OF *Aspergillus niger* MYCELIUM

The influence of size of inoculum on the weight of mycelium was determined in an experiment using 0.1-, 0.5-, 1.0-, 2.0-, and 5.0- cc spore suspensions for inoculation. Two hundred p.p.m. of phosphorus as $CaH_4(PO_4)_2.H_2O$ were added to 60 cc of the Niklas phosphorus-free medium. Four flasks with each inoculation were incubated and the weight of mycelium determined as in the above experiments. The results obtained are shown in Fig. 5.

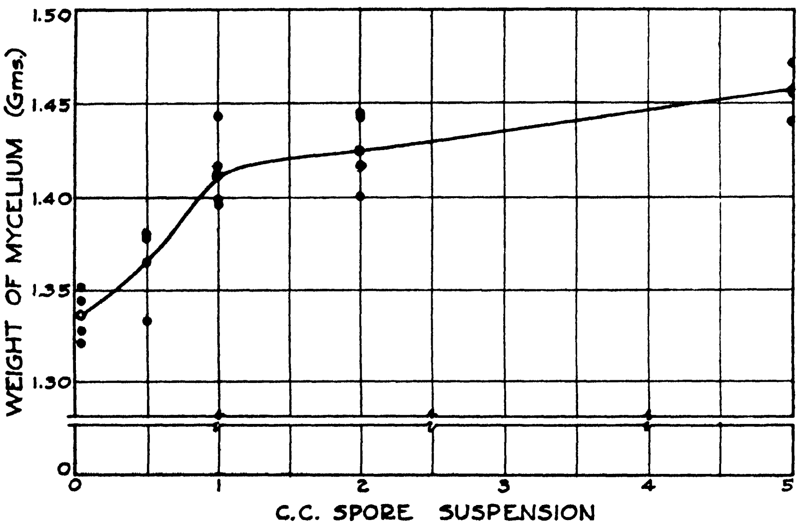

FIG. 5.—Effect of size of inoculum on weight of mycelium.

The data show that there was a rather sharp increase in the weight of mycelium with an increase in the size of inoculum up to 1.0 cc. There was also a small average increase in the weight of mycelium with an increase in the size of inoculum above 1.0 cc. These results undoubtedly explain the variation in weight of mycelium of replicate cultures.

4. RELATION BETWEEN WEIGHT OF MYCELIUM AND CONCENTRATION OF PHOSPHORUS IN SOIL

Additions of phosphorus as $CaH_4(PO_4)_2.H_2O$ to 3.5 grams of soil were made to determine the influence of the soil in the medium on the relationship between the weight of mycelium to concentration of phosphorus. The concentration of phosphorus was varied at intervals of 10 p.p.m. up to 100 p.p.m. Four flasks for each concentration of phosphorus were inoculated, incubated, and the weight of mycelium determined. The results obtained are presented in Figs. 6 and 7.

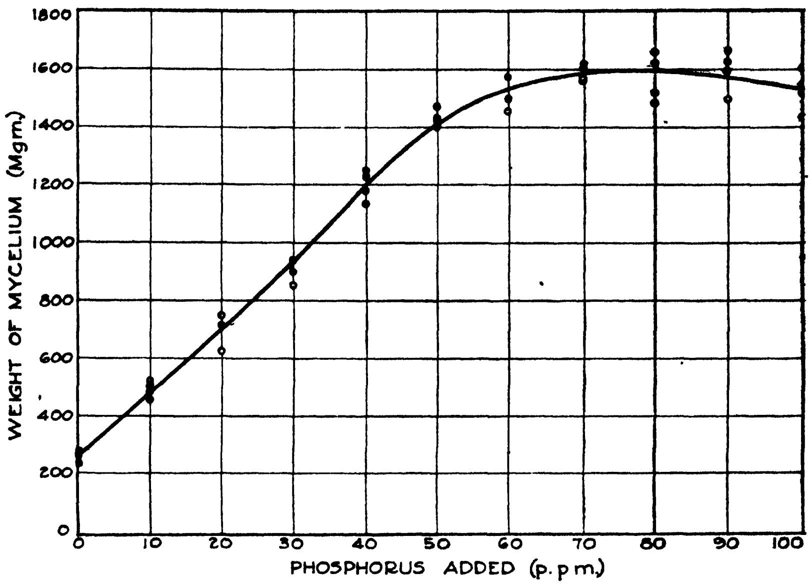

FIG. 6.—Effect of soil and phosphorus on the weight of ***Aspergillus niger*** mycelium.

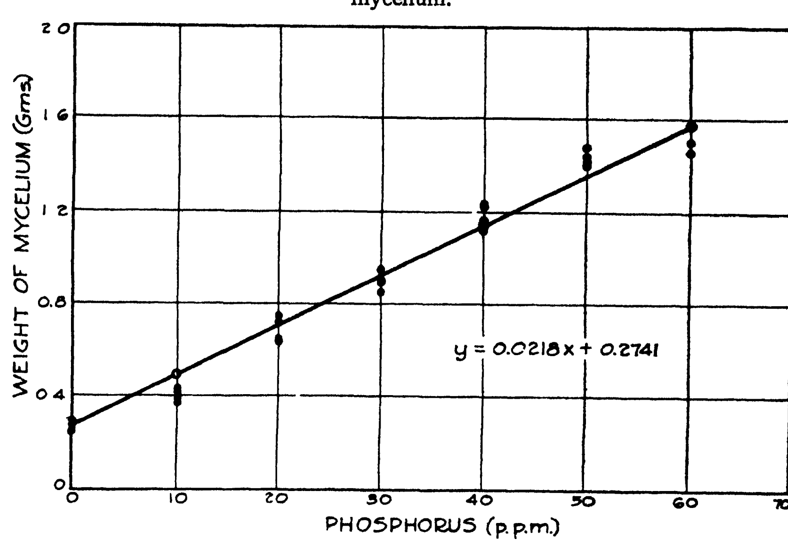

FIG. 7.—Relation of weight of *Aspergillus niger* mycelium to concentration of phosphorus in soil medium.

The data show that the weight of mycelium increased directly as the concentration of phosphorus increased up to about 60 p.p.m. of phosphorus. Plotting the weight of mycelium against the concentration of phosphorus in the range 0 to 60 p.p.m. of phosphorus gives a fairly straight line (Fig. 7).

5. RELATION BETWEEN WEIGHT OF MYCELIUM AND AMOUNT OF SOIL IN MEDIUM

The addition of soil to the medium in the preceding experiment brought about a different relationship between the weight of mycelium and the concentration of phosphorus than was obtained when the mycelium was grown in a soil-free medium. In this experiment

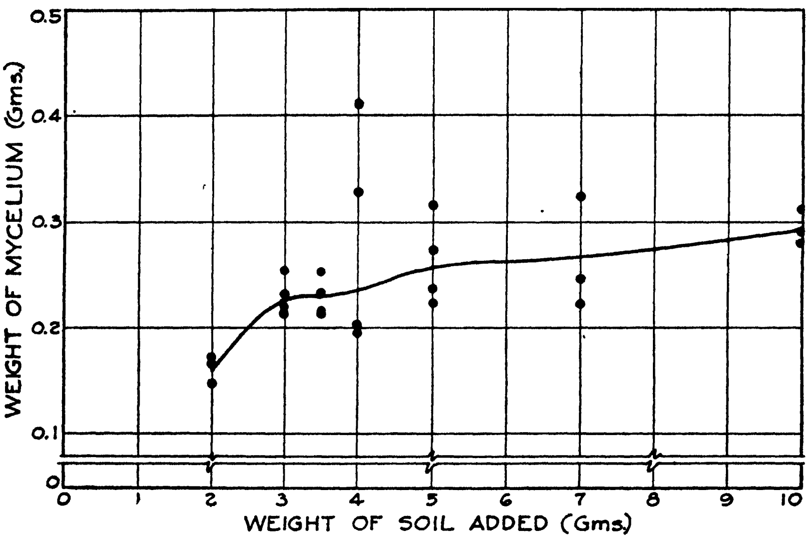

FIG. 8.—Effect of soil added to medium on the weight of *Aspergillus niger* mycelium.

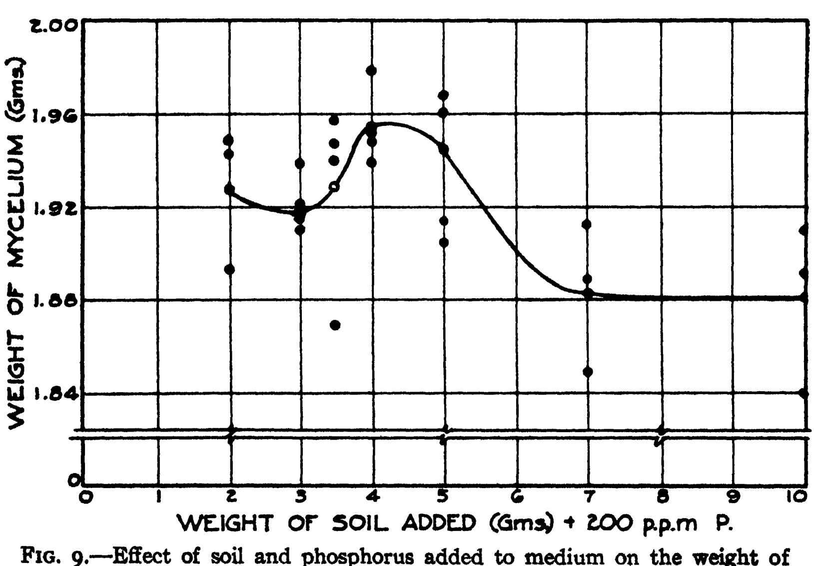

FIG. 9.—Effect of soil and phosphorus added to medium on the weight of *Aspergillus niger* mycelium.

different amounts of soil were added to a phosphorus-free medium in one series and the same amounts of soil added to the medium in another series which contained 200 p.p.m. of phosphorus. The results obtained are shown in Figs. 8 and 9.

A small average increase in the weight of mycelium was obtained with an increase in the amount of soil added up to 4 grams of soil, where no phosphorus was added in addition to that contained in the soil (Fig. 8). There was a considerable variation in the weight of mycelium in the replicate cultures above 3.5 grams of soil added where 200 p.p.m. of phosphorus were added in addition to the soil. The highest average weight of mycelium was obtained at 4 grams of soil but the weight of mycelium of three of the four cultures at 3.5 grams of soil averaged as much as the weight of mycelium at 4 grams. With an increase in the amount of soil added where phosphorus was also added (Fig. 9), there was a tendency for the weight of mycelium to decrease. This was probably brought about by a fixation of phosphorus by the soil or by the activity of other micro-organisms.

6. RELATION BETWEEN VOLUME OF MEDIUM TO WEIGHT OF MYCELIUM

The influence of volume of medium on the weight of mycelium was determined by inoculating flasks containing 30, 60, 90, 120, 150, and 180 cc of the phosphorus-free medium to which 3.5 grams of soil had been added. The weight of mycelium was determined after 6 days incubation. The curve (Fig. 10) is drawn through the average weights of the four replicate cultures.

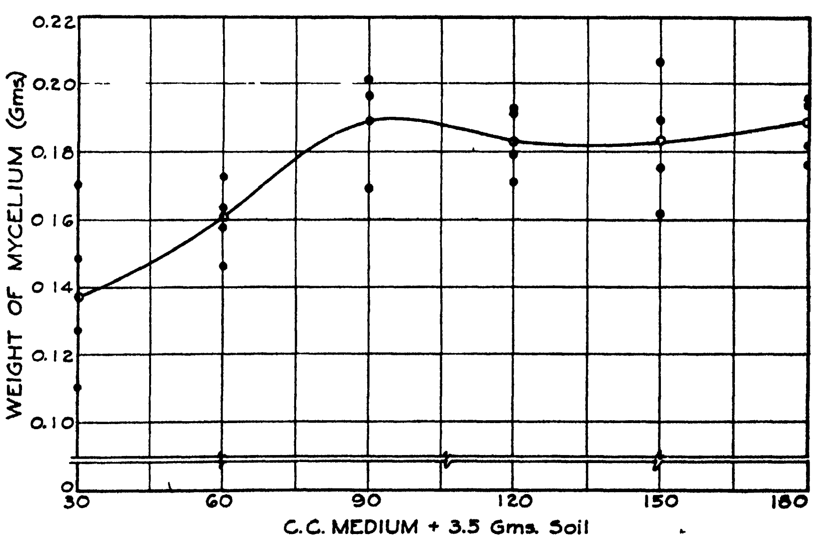

FIG. 10.—Effect of volume of medium on the weight of *Aspergillus niger* mycelium.

The data show quite a variation in the weight of individual pads, but the average weight of mycelium increased with an increase in the

volume of medium up to 90 cc. There was a slight decrease in the weight of mycelium with 120 cc and 150 cc of medium over that obtained with 90 cc of medium.

7. WEIGHT OF MYCELIUM FROM DIFFERENT FORMS OF PHOSPHATE

The relationship between the weight of mycelium and the concentration of phosphorus was different in the soil-free medium than when soil was added. This change in relationship may be due in part to the addition of forms of phosphorus in soil other than mono-cal-

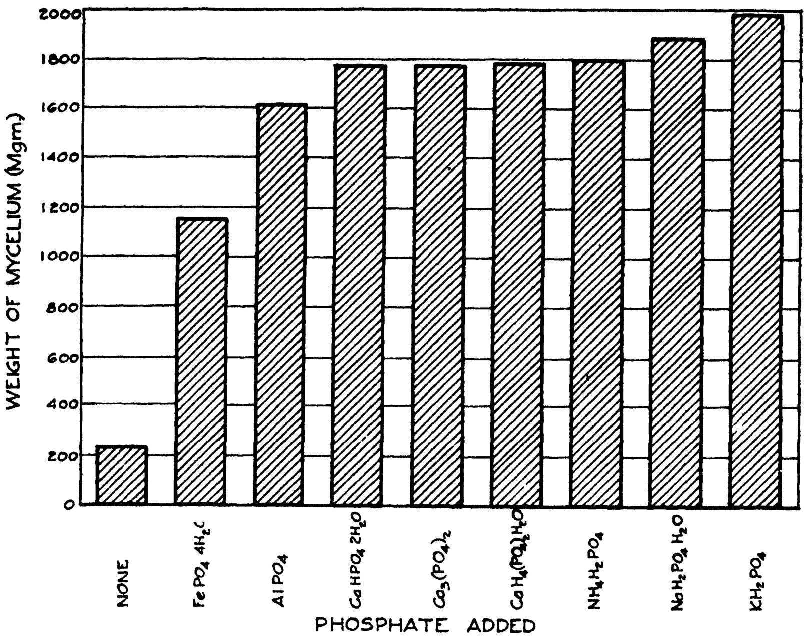

FIG. 11.—The weight of *Aspergillus niger* mycelium grown on different phosphates.

cium phosphate which was used in the soil-free medium. A series of flasks were inoculated which contained 200 p.p.m. of phosphorus supplied by different common soil phosphates. After incubation the weight of mycelium was determined and the average weight of the four replicate cultures given for each phosphate (Fig. 11).

The average weight of mycelium was about the same for the three calcium phosphates. The average weight of mycelium was increased slightly in the ammonium, sodium, and potassium phosphates, respectively, over that obtained with calcium phosphates. The weight of mycelium obtained with iron and aluminum phosphates was decreased under that obtained with the calcium phosphates. These differences were probably caused by a difference in the solubility of the different phosphates or to the effect of the different cations on the growth of the mold.

DISCUSSION OF RESULTS

The amount of phosphorus taken up by *Aspergillus niger* and *Cunninghamella* sp. increased with increasing concentrations of phosphorus in the medium, but the variation between the amount of phosphorus assimilated by duplicate cultures was large and not significantly correlated with the weight of mycelium. The Niklas medium was more favorable for the growth of *Aspergillus niger* than a dextrose-peptone medium, but *Cunninghamella* sp. did not make a satisfactory growth in the Niklas medium.

The relationship between the weight of *Aspergillus niger* mycelium in the Niklas medium over a range in phosphorus concentration from 0 to 500 p.p.m. was represented by an exponential curve. However, a different type of curve was obtained when the experiment was repeated to obtain a larger number of points on the curve over a smaller range of concentrations of phosphorus. The chief reasons for the variations in the relationship of weight of mycelium to the concentration of phosphorus in the medium in the different experiments were undoubtedly a difference in the number of spores used for inoculation, the viability and the efficiency of the spores used, the volume of medium, and the length of incubation period, as well as the natural variation between cultures of the same organism. That all of these factors were important in determining the weight of mycelium in a given concentration of phosphorus was demonstrated in several experiments.

A different relationship between the weight of mycelium and the concentration of phosphorus was obtained when soil was added to the medium than when a soil-free medium was used. In the presence of the soil used, Carrington loam, the weight of mycelium obtained was directly proportional to the amount of phosphorus present in the medium over the range from 0 to about 60 p.p.m. of phosphorus. This relationship was characteristic of Carrington loam under the conditions of the experiment. That the above relation would vary with different soils is emphasized by the results obtained when different forms of phosphate were used and that it would vary with the same soil under different conditions is brought out by the results obtained by varying the amount of soil added or the volume of medium employed.

The results of these experiments show that the growth of *Aspergillus niger* in the Niklas medium to which soil has been added may be used to indicate roughly the amount of phosphorus available to *Aspergillus niger*, but that any attempt to interpret the results of such tests as showing quantitatively the amount of available phosphorus in the soil is likely to lead to erroneous conclusions. It may serve as a qualitative test if the technic employed is carefully standardized. For the soil used in these experiments 4 grams of soil in 90 cc of medium in a 250-cc extraction flask with a 1 cc suspension of spores 6 to 10 days old for incubation and an incubation period of 6 days seemed most satisfactory.

SUMMARY AND CONCLUSIONS

Experiments were conducted in a study of phosphorus assimilation by *Aspergillus niger* and *Cunninghamella* sp. to determine the relationship of the weight of mycelium to the concentration of phosphorus in the medium. It was found that the weight of *Aspergillus niger* mycelium in Niklas medium to which soil was added was roughly proportional to the concentration of phosphorus in the medium over the range from 0 to about 60 p.p.m. of phosphorus.

It was concluded that the weight of *Aspergillus niger* mycelium in the Niklas medium to which soil has been added may be used to indicate roughly the amount of phosphorus available to *Aspergillus niger* if the technic employed is carefully standardized. Whether or not the phosphorus available to *Aspergillus niger* represents the amount of phosphorus available to crop plants was not determined.

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REGISTRATION OF VARIETIES AND STRAINS OF OATS, VII[1]

T. R. STANTON[2]

THE sixth report on the registration of improved oat varieties was submitted in 1934 and published in January, 1935.[3] Only one improved strain of oats, a winter variety, was submitted and approved for registration in 1935. It is as follows:

Group and Varietal Name	Reg. No.
Midseason gray:	
Support	83

A summary of the available information on description, performance, and potential value of this new variety, on which approval for registration is based, is given in the following paragraphs:

Support (C. I. No. 3180) was originated in 1926 as a plant selection known as "Number 5" from unlabeled plant material at the Oregon Agricultural Experiment Station, Corvallis, Ore., by H. A. Schoth.[4] So far it has not been possible to determine whether this selection arose from unfixed hybrid material furnished by the Division of Cereal Crops and Diseases from the Arlington Experiment Farm, Rosslyn, Va., to E. N. Bressman, formerly of the Oregon Agricultural Experiment Station, in the falls of 1924 and 1925, or from stocks grown previous to 1924 at Corvallis by C. C. Ruth. Strain No. 5 was subsequently developed and multiplied by H. A. Schoth, who applied for its registration. Support was first distributed to farmers in 1931.

Support is a midtall to tall, midseason, gray-seeded winter common oat similar to Winter Turf (Oregon Gray). The superior characters of Support are high yield, stiff straw, thin hull, heavy stooling, and rust-evasion in western Oregon. Under the conditions at Corvallis, Support is about 10 days earlier than Winter Turf and is an excellent support crop for annual viny legumes such as vetch. The writer observed Support grown in nursery rows this past season at the Arlington Experiment Farm and at the Aberdeen Substation, Aberdeen, Idaho, from fall and spring seeding, respectively. Support is undoubtedly very similar to Winter Turf, yet there is a difference in the color of the straw and general appearance of the plant during the ripening period that distinguishes it from the older variety. At Aberdeen, Idaho, Support ripened fully 6 days in advance of Winter Turf and developed a more distinct grayish lemma. At the Arlington Exper-

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[1]Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication November 26, 1935.

[2]Senior Agronomist in Charge of Oat Investigations, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1935 Committee on Varietal Standardization and Registration, charged with the registration of oat varieties.

[3]STANTON, T. R. Registration of varieties and strains of oats, VI. Jour. Amer. Soc. Agron., 27: 66–70. 1935.

[4]Associate Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

iment Farm it ripened only 2 days ahead of the earlier Winter Turf strains and appeared to be about equally winter resistant. At the former station, Support thus showed some evidence of being of hybrid origin, while at the latter it appeared simply to be an early strain of Winter Turf.

Support was tested in duplicated 1/20 acre plats from 1927 to 1931 at Corvallis. The annual and average acre yields of Support and Winter Turf, the standard winter oat of western Oregon and Washington, are given in Table 1.

TABLE 1.—*Annual and average acre yields of Support and Winter Turf (Oregon Gray) winter oat varieties grown at the Oregon Experiment Station, Corvallis, Ore., 1927–31.*

Variety	Acre yield, bushels					
	1927	1928	1929	1930	1931	Average
Support	61.9	85.0	88.1	79.4	81.3	79.1
Winter Turf	66.1	64.6	72.6	65.9	65.4	66.9

Interest in Support is rapidly increasing among farmers in western Oregon where fall-sown oats are relatively important. Mr. H. A. Schoth, in a letter addressed to the writer under date of September 4, 1935, reports on Support as follows: "There was a considerable acreage of this oat grown in western Oregon this year. There was also a smaller acreage grown in western Washington. Crops in each case were reported as being very good and the quality of the grain as excellent."

BOOK REVIEWS

TRANSACTIONS OF THE THIRD INTERNATIONAL CONGRESS OF SOIL SCIENCE

Vol. I. Commission Papers. XII + 428 pages, illus. 1935. Vol. II. Plenary Session Papers and Presidential Address. VI + 194 pages, illus. 1935. London: Thomas Murby & Co.

THESE two volumes, together with a third which is not yet available, make up the report of the transactions of the Third International Congress of Soil Science. Although they represent the customary report which follows each Congress, there are a number of important and desirable changes in general form.

Volume I contains the papers presented before the various Commissions of the Congress. The papers, 156 in number, are classified and arranged with reference to specific subjects under each of the nine Commissions and Sub-commissions. The table of contents shows the papers to be arranged under 30 different general subjects, consecutively as to Commissions and alphabetically as to the contributors to these subjects. This arrangement makes it almost as easy to find specific authors or subjects as if the volume were regularly indexed.

Volume II contains the Presidential address and the plenary session papers of the various Commissions. These include 15 complete papers or from two to three for each of the six Commissions. In both volumes, the papers of the German and French contributors are printed in those languages, while all others are in English.

These two volumes, together with the third one of the report, should give the worker in the various fields of soil science an excellent picture not only of what other soil workers are doing, but also what they are thinking in this important and fundamental branch of science. (R. C. C.)

THE USE AND MISUSE OF LAND

By R. Maclagan Gorrie. New York: Oxford University Press (Oxford Forestry Mem. No. 19). 80 pages, illus. 1935. $2.00.

IN these days when so much attention is being centered on soil conservation, this book should be of unusual interest. The author, through the generosity of a Leverhulme Research Fund, was able to make a four months' tour of the United States. The original purpose was to study the influence of grazing upon soil erosion. The report, however, deals with a much broader field, including several other abuses of both forest and farm lands. The survey was conducted largely in the western states and, therefore, the conclusions are largely applicable to that area.

An idea of the scope of the book can be secured by noting the eight main chapter headings which are as follows: I. Forestry as a Factor in Land Management; II. Grazing and Range Management; III. Over-grazing as a Primary Cause of Soil Erosion; IV. Value

of Vegetational Cover in Stream Flow Control; V. Forestry as a Factor in Farm and Village Economy; VI. Farm Erosion and Its Control; VII. Other Examples of the Misuse of Land; and VIII. Public and Private Control of Land.

The book contains descriptions of many recent soil erosion investigations and presents many actual data secured as a result of these investigations. Also, the writer gives his ideas as to possible ways of cutting down the serious erosion losses which occur on mismanaged lands.

The book should be of equal value to those interested in soil erosion research and to those concerned primarily with the broader aspects of land management policies. (R. F. C., Jr.)

THE DESIGN OF EXPERIMENTS

By B. A. Fisher. Edinburgh: Oliver and Boyd. IX + 252 pages, illus. 12/6 net. 1935.

THIS new book by Dr. Fisher brings together in one volume most of the later studies in experimental technic which have been developed by himself and other workers. In it, the author emphasizes particularly the fundamental principles of experimental design with the aim of making the use of analysis of variance applicable to the data. The book is not a review of technic used by other workers, nor does it consist of a collection of diagrams of plat arrangement, although numerous illustrative examples are given. It is rather difficult in a brief review to give a comprehensive account of the vast amount of information that is condensed in this work. Perhaps most readers will get a better idea of the scope of the work from a listing of the chapter headings and brief discussions of these than from more general statements.

The introductory chapter deals largely with the logic of inductive inference. In Chapter II, entitled "The Principles of Experimentation Illustrated by a Psycho-physical Experiment", there are considered the test of significance, the null hypothesis, randomization, etc. Chapter III is devoted to a description of Darwin's experiments in cross- and self-fertilization of plants, together with various interpretations of the data. Chapter IV is entitled "Agricultural Experiment in Randomized Blocks" and in it are discussed the general principles of plat arrangement and statistical analysis of the observations. "The Latin Square" is the title of Chapter V in which are considered, among other subjects, faulty treatment of square designs, systematic squares, and Graeco-Latin and higher squares.

"The Factorial Design in Experimentation" (Chapter VI) should prove of considerable interest to those workers who, because of the number of tests, are either unable to make many replications or who desire to get the most out of field tests that have few or even no replications. Chapter VII, "Confounding" is an extension of the factorial scheme, while Chapter VIII considers "Special Cases of Partial Confounding". "The Increase of Precision by Concomitant Measurement, Statistical Control" (Chapter IX) is a discussion of suitable occasions for concomitant measurements, arbitrary correc-

tion, and the test of significance. Chapter X, "Generalization of Null Hypotheses, Fiducal Probability" is concerned with various tests, such as the t test, the X^2 test, and wider tests based on the analysis of variance. Chapter XI, "The Measurement of Amount of Information in General" places in a brief space consideration of the following subjects: Estimation in general, frequencies of two alternatives, functional relationships among parameters, the frequency ratio in biological assay, linkage values inferred from frequency ratios and from the progeny of self-fertilized or inter-crossed heterozygotes, information as to linkage derived from human families, information elicited by different methods of estimation, and information lost in the estimation of error. Numerous practical examples are given throughout the book.

It is difficult to see how any investigator, and especially those workers who deal with agricultural experiments, can fail to find a wealth of information and assistance in this unique work. It should be on the desk of every worker. (F. Z. H.)

DICTIONARY OF TERMS

By T. J. Bezemer. Baltimore: Williams & Wilkins Co. VII + 1062 pages. 1935. $8.

TO say that this book is unique is to state the obvious when one considers that it is an attempt to bring together in one volume a list of English, French, Dutch, and German terms commonly used in general agriculture, horticulture, forestry, cattle breeding, and dairying as an aid to the student in finding exact equivalents of technical terms encountered in foreign textbooks and works of reference. The fact that American workers will have their curiosity aroused at once as to the basis for the selection of the terms listed in the volume does not detract in the least from the value of the work with respect to the terms that are included. The compiler makes no claim to completeness and points out that preference has been given to those terms believed to have the greatest importance in their particular field. For example, it is stated that to name all of the useful and injurious insects would require a volume in itself, hence in the present work will be found "only those which are most important for agriculture in the widest sense of the term".

The volume has been compiled by Professor Bezemer with the assistance of several of his colleagues at the State Agricultural College at Wageningen, Holland, and is divided into four parts, *viz.*, English, Dutch, French, and German. This enables the user when employing any one of these languages to find the equivalents of the term in the three other languages. For example, under "Wheat" in the English section, one finds the following entry:

wheat.—Weizen *m.*—**tarwe** *f.*—**froment** *m.*, **blé** *m.* (*Triticum* **sp.**)

One might question the use of the word "Dictionary" in connection with such a volume, which would be more exactly described as a "Glossary", since no attempt is made to trace the derivation of the terms or to define them. This is of minor importance, however, so

long as one understands the purpose and content of the volume. Certainly it will prove an invaluable aid to the abstractor, to the librarian, and to everyone in fact who reads extensively in the agricultural literature of these four languages. (J. D. L.)

ERGEBNISSE DER AGRIKULTURCHEMIE

By F. Alton and M. Trénel. Berlin: Verlag Chemie, G. M. B. H. 156 pages, illus. 1935. RM 8.

THIS is Volume 3 of the proceedings of the 47th Congress of the Verein Deutscher Chemiker in Koln in 1934. It contains a general article by H. Niklas on the rôle of agricultural chemistry in the new Germany and three groups of papers on soils and fertilizers, animal nutrition, and agricultural technology. Most of the articles are reviews rather than presentation of new data.

The field of soil chemistry in relation to the determination of nutrient requirements is discussed in several papers. The article of R. Thun on the organization and work of the small experimental cooperative organizations (Versuchsringe) will be of general interest to agronomists because of the success of these establishments in Europe.

Other articles on soils and fertilizers are from F. Alton, W. U. Behrens, Trénel and Alton, L. Schmidtt, and C. Pfaff. The articles on animal nutrition are by A. Scheunert, A. Jacob, L. Seidler, and W. Wöhlbier. The problem of sugar production from wood and its utilization as feed is discussed by Spengler und H. Claassen.

The reader of this volume obtains a good cross-section of the present position and future problems of practical agricultural chemistry in Germany. (Z. I. K.)

FELLOWS ELECT

ALBERT CEDRIC ARNY

ALBERT CEDRIC ARNY, College of Agriculture, University of Minnesota, St. Paul, Minnesota. Born at Newport, Minnesota, November 4, 1877. B.S.A., University of Minnesota 1909; M.S., University of Minnesota 1918. Assistant Professor of Agronomy, University of Minnesota 1909–1916; In Charge of Farm Crops Section, Division of Farm Management, Agronomy, and Plant Genetics, 1914–1927; Associate Professor of Agronomy and Associate Agronomist, 1916—.

Member of American Society of Agronomy; Minnesota Academy of Science. While his special interests include crop rotations, forage crops, weed eradication, and flax breeding, he is also greatly interested in all other phases of agronomic work as shown by numerous publications.

Professor Arny has been a member of the Society for many years, has been a member of several standing committees, and was chairman of the Committee on Intercollegiate Crop Judging Contests.

RICHARD BRADFIELD

RICHARD BRADFIELD, Ohio State University, Columbus, Ohio. Born on a farm near West Jefferson, Madison County, Ohio, April 29, 1896, where his family were some of the pioneer settlers of the county. B A , Otterbein College, Westerville, Ohio, 1917; Ph.D., Ohio State University, 1922. Instructor in Soils, University of Missouri, 1920–1922; Assistant Professor of Soils, 1922–1923; Associate Professor 1923–1930; Guggenheim Fellow, Kaiser Wilhelm Institute, Berlin, Germany, 1927–1928; Professor of Agronomy, Ohio State University 1930—; Associate in Agronomy, Ohio Agricultural Experiment Station, 1930—.

Member A.A.A.S.; American Society of Agronomy; American Soil Survey Association; International Society of Soil Science; American Chemical Society; Ohio Academy of Science. His special interests include physical-chemical relationships of soils, especially of soil colloids. Dr. Bradfield's interests in soil investigations have been cen-

tered around soil colloids but with a great concern in the problems of practical agriculture.

Dr. Bradfield has served on various committees of the Society and has participated in the programs of many annual meetings. As a member of the Committee on Reorganization of the Society in 1931, and as chairman of the Joint Committee for Reorganization of Soil Science Societies in 1935, he has contributed much to the progress of the Society and of soil science in America.

CHARLES ERNEST MILLAR

CHARLES ERNEST MILLAR, Michigan State College; Michigan Agricultural Experiment Station, East Lansing, Michigan. Born at Mattoon, Illinois, June 23, 1885. B.S., University of Illinois, 1909; Graduate Assistant, University of Illinois 1909–1910; Assistant Chemist, Kansas State Agricultural College, 1910–1911; M.S., Kansas State Agricultural College, 1911; Assistant in Soils, 1913–1915; B.S. in Agriculture, Kansas State Agricultural College, 1915; Assistant Professor of Soils, Michigan State College, 1915–1918; Associate Professor, 1918–1925; Ph.D., University of Wisconsin, 1923; Professor of Soils, Michigan State College, 1925; Head of Department of Soils, Michigan State College, 1930—.

Member of American Society of Agronomy and American Soil Survey Association. While his special interests have been in soil fertility and land utilization, he has much interest in all phases of agronomic work.

Dr Millar has served on many special committees, and is now chairman of the Soils Section of the Society.

MINUTES OF THE TWENTY-EIGHTH ANNUAL MEETING OF THE SOCIETY

The twenty-eighth annual meeting of the Society was called to order by President H. K. Hayes of the University of Minnesota, at 9:00 a. m. on Thursday, December 5, 1935, at the Stevens Hotel, Chicago, Ill. There were 388 members registered during the meeting and considerably over 400 were in attendance at the various sessions.

The general program, which consisted of a symposium on "Regional Land Use", was given as follows:

1. In the Hard Red Spring Wheat Region. H. L. Walster, North Dakota State College.
2. In the Hard Red Winter Wheat Region. R. I. Throckmorton, Kansas State College.
3. In the Corn Belt. P. E. Brown, Iowa State College.

The annual dinner featuring the address of the president "Green Pastures for the Plant Breeder" (pages 957 to 962 of this number of the JOURNAL), was held on Thursday evening. The Crops and Soils Sections and Sub-sections presented programs on Thursday afternoon and on Friday and the Extension Section gave a program on Thursday afternoon. There were two sectional programs in Crops and three sectional programs in Soils on Friday. The International Crop Improvement Association meeting was held on Wednesday, December 4, with the Society, and the American Soil Survey Association met on Tuesday and Wednesday jointly with the Agronomy Society, and joined in the programs of the Soils Section and Sub-sections on Thursday and Friday. The Soybean Council met on Thursday at the noon hour and the Joint Committee on Fertilizer Applications with its two sub-committees met on Tuesday and Wednesday with arranged programs.

The President appointed the Auditing Committee, consisting of Dr. Richard Bradfield, *Chairman*, and Dr. H. K. Wilson. The Nominating Committee consisted of President Hayes, *Chairman*, Dr. A. L. Patrick and Dr. W. A. Albrecht from the Soils Section, and Prof. H. B. Sprague and Prof. A. M. Brunson from the Crops Section.

COMMITTEE REPORTS

VARIETAL STANDARDIZATION AND REGISTRATION

Dr. M. A. McCall, *Chairman*, presented the report of the Committee on Varietal Standardization and Registration, which, upon motion, was adopted as follows:

Since the last annual meeting, the Committee on Varietal Standardization and Registration has approved the registration of three wheat varieties, Clarkan, Comet, and Hymar, and of one oat variety, Support. The data on which registration is based are being submitted for publication elsewhere in the JOURNAL.

The Committee also reports progress on the registration of cotton varieties. A joint sub-committee of this Society and of the Agronomy Section of the Association of Southern Agricultural Workers, under the chairmanship of Dr. H. B. Brown of the Society Committee, after a careful survey and study, has prepared a list of 31 varieties which are recommended for adoption as standard varieties. These varieties were all in commercial production in 1930. They are as follows:

1. Acala-5
2. Acala-8
3. New Boykin
4. Cleveland-5
5. Cleveland-884
6. Piedmont Cleveland
7. Wannamaker Cleveland
8. Cook-307-6
9. Delfos
10. Delta and Pine Land-8
11. Delta and Pine Land-10
12. Deltatype Webber
13. Dixie-Triumph
14. Dixie-14
15. Express-121
16. Lightning Express
17. Half and Half
18. Kasch
19. Lone Star
20. Mebane
21. Missdel
22. Station Miller
23. Mexican Big Boll
24. Oklahoma Triumph-44
25. Pima
26. Rowden
27. Arkansas Rowden -40
28. Toole
29. Stoneville
30. Trice
31. Wilds

The preparation of adequate descriptions of these varieties involves many technical difficulties. Accordingly, a more or less preliminary description of each variety has been prepared, which is to be published elsewhere in the JOURNAL. A more complete study from which it is intended to develop a more adequate and complete description is being undertaken; but since this will require several years for completion, it is felt that the publication of preliminary descriptions is advisable. The descriptions as now prepared are in a form which it is believed will be useful in the preliminary stages of standardization and registration.

During the year a request was received for registering a variety of rye. Standards for the registration of this crop have not been adopted, and the matter is being submitted to the committee for consideration.

A U. S. Dept. of Agriculture technical bulletin on the classification of American sorghum varieties will shortly come from the press. Pending the appearance of this classification, your committee has delayed plans for registering sorghum varieties. It is expected that a plan will be submitted to the Society at its next annual meeting.

During the year there has been issued a revision of U. S. Dept. of Agriculture Bul. 1074, "Classification of American Wheat Varieties". This new classification, U. S. Dept. of Agriculture Tech. Bul. 459, "Classification of Wheat Varieties Grown in the United States", contains the descriptions of 77 new varieties not in the previous publication. Of these 77 varieties, 42 have been registered by the Society as improved varieties. The remaining 35 are not registered but are in commercial production. In registering as standard varieties the varieties named in the original list given in Department Bul. 1074, the Society recognized the principle that commercial production justified registration as a standard variety, but not as an improved variety. It would seem, therefore, that the 35 new varieties included in the new classification also should be registered as standard varieties. These new varieties and their suggested registration numbers are as follows:

Varieties	Registration Nos.	Varieties	Registration Nos.
Wilhelmina	279	Montana King	291
Escondido	280	Pusa 4	292
Oregon Zimmerman	281	Missouri Valley	293
Currawa	282	Red Indian	294
Redhart	283	V. P. I. 131	295
Renfrew	284	Marvel	296
Arco	285	Early Blackhull	297
Golden	286	Superhard	298
Powerclub	287	Cooperatorka	299
Hard Federation 31	288	Eagle Chief	300
Axminster	289	Nebraska No. 6	301
V. P. I. 112	290	Utah Kanred	302

Enid	303	Kruse	309
Redhull	304	Poso	310
Sea Island	305	Genro	311
Whiteman	306	Hood	312
Berkeley Rock	307	Barnatka	313
Hyper	308		

In summary, the following recommendations are presented to the Society for action:

1. The 31 cotton varieties listed above shall be recognized by the Society as standard varieties.
2. The 35 wheat varieties listed above shall be recognized as standard varieties.

H. B. BROWN — W. J. MORSE
J. A. CLARK — J. H. PARKER
E. F. GAINES — T. R. STANTON
H. K. HAYES — G. H. STRINGFIELD

M. A. MCCALL, *Chairman*

EDUCATION IN AGRONOMY

Dr. R. J. Garber, *Chairman*, gave the report of the Committee on Education in Agronomy. Upon motion the report was accepted as follows:

The Committee on Education was fortunate in that it was assigned a specific task, namely, "to take up with the American Council on Education the matter of consideration and inclusion of the applied agricultural fields of work, in the studies of the Committee on Graduate Instruction of that council." By correspondence at infrequent intervals throughout the year your committee draw up suggestions regarding graduate work in agronomy and early in November transmitted them to Dean F. B. Mumford of the University of Missouri who was designated by the Executive Committee of the Association of Land Grant colleges and universities to act as liaison officer. The suggestions which are made a part of this report follow.

The Committee on Education of the American Society of Agronomy would like to call attention to the need for graduate instruction in the applied fields of agriculture, as well as in the underlying foundation sciences. While instruction in the latter is more fundamental and more necessary for satisfactory graduate training than is similar instruction in the applied fields of agriculture, it is nevertheless true that persons who expect to engage in agricultural research should be trained in agriculture as well as in the foundation subjects. The possibility of teaching fundamentals by using materials from the applied fields should not be overlooked. An institution which is equipped to offer adequate instruction both in the foundation and applied subjects is perhaps best fitted to offer graduate instruction for students in agriculture. On the other hand, it should be recognized that there are a number of institutions which excell in the quality of the graduate facilities offered, either in essential foundation sciences or in some highly specialized field of agriculture. Through cooperative arrangement, it should be possible for a student to pursue graduate studies in both these classes of institutions without unnecessary loss of time in attaining the desired degree. The value of graduate training in highly specialized fields of agriculture for students who expect to enter such highly specialized fields is apparent.

The Committee on Education in Agronomy believes that while the number of students pursuing graduate instruction in the several subdivisions of agronomy should not be arbitrarily limited for the present, it should nevertheless be the

definite policy of responsible persons to encourage only the noticeably superior students to do graduate work. Stipends to worthy graduate assistants who possess superior ability are very worth while expenditures, but stipends to graduate students who are chosen primarily because they provide a cheap source of help in the laboratory or field routine are questionable. If agronomic research is to be maintained on a high plane, only high class students should be encouraged to engage in it.

The Committee on Education of the American Society of Agronomy is in sympathy with the purpose of attempting an evaluation of the various institutions offering graduate instruction such as was made by the Committee on Graduate Instruction of the American Council on Education, and covered in the report issued by that committee in April, 1934. It is believed, however, that the limitations of such surveys should be clearly recognized and the results presented only as a general guide for prospective graduate students. The two most dominating influences in the mind of a candidate in selecting an institution are the location of the major professor under whom the student wishes to study and, perhaps to a less extent, the amount of stipend, if any, he is to receive. The results of a survey such as the one mentioned above should serve to give the student supplementary information. The Committee believe that such supplementary information would be more useful to students of agriculture, and particularly in agronomy, if the relative strength of the various institutions in the subdivisions of the subject are revealed. As a guide to a workable classification in making such a survey, it is suggested that the subdivisions in agriculture in which major work is now offered for the doctorate in the various agricultural colleges be used. For agronomy this might include, in addition to the foundation subjects, the five subdivisions of soil fertility and chemistry, soil biology, soil morphology and classification, crop breeding, and crop production. There also exists a need for advanced training in crop morphology, crop ecology, and crop physiology. For the present, perhaps, this need may best be met by those institutions which offer satisfactory graduate training in crop production and in the necessary foundation subjects of plant physiology, ecology, and morphology. A suitable combination of fundamental and applied subjects for the advanced student of agronomy may also be provided through cooperation between two institutions.

It may be desirable in some instances to designate subdivisions of foundation subjects. For example, genetics certainly is fundamental to the study of plant breeding and the student in this field prefers to study plant genetics rather than animal genetics. It may be well, therefore, to obtain separate appraisals of these divisions of the foundation subjects. In a similar manner physiology may be divided into plant physiology and animal physiology.

Another feature of vital importance to a survey such as was conducted under the auspices of the American Council on Education is the personnel of the group who make up the appraisals on which the relative standing of institutions is based. With respect to agronomy it is suggested that at least 50% of the persons making up the group be actively engaged in research and not merely active in an administrative capacity. To the Committee it seems that a more just appraisal is likely to be obtained if the group charged with the responsibility of making the appraisals is composed about equally of younger men actively engaged in research in the particular subdivision under consideration and older and more experienced individuals who at present may be spending most of their research time directing others.

If surveys similar to the one mentioned above are to be useful, they must give up-to-date information. To do this a survey should be made at least once every five years, and when it is made, it should be done promptly and the report covering it published immediately.

RICHARD BRADFIELD LEROY POWERS
JOHN H. PARKER R. J. GARBER, *Chairman*

BIBLIOGRAPHY OF FIELD EXPERIMENTS

Dr. H. M. Steece, *Chairman*, presented the report of the Committee on Bibliography of Field Experiments. It was moved and carried that the report be accepted and printed in the JOURNAL as follows:

The committee has compiled a bibliography of 134 titles of the more important contributions on the methodology of and interpretation of results of field plat experiments, either reported since or not included in the revised bibliography published in the JOURNAL. (Vol. 25: 811–828. 1933.)

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F. R. IMMER J. T. MCCLURE
T. A. KIESSELBACH H. M. STEECE, *Chairman*

PASTURE RESEARCH

Prof. A. E. Aldous gave the report of the Committee on Pasture Research, which upon motion was accepted as follows:

Strenuous attempts were made during the past year to combine the report on pasture investigations technic presented by this Committee November 22, 1934, with similar reports from committees of the Dairy Science Association and the American Society of Animal Production. These efforts have been unavailing, probably because of the inability of representatives of the three committees to meet at any time for conference. In the absence of this much-desired joint report, your committee wishes to present for consideration and publication, if approved, a report on the technic of grazing investigations in the arid and semiarid regions. This report was prepared by Dr. George Stewart with the assistance of W. R. Chapline and Wm. A. Dayton, all of the Division of Range Research, Forest Service, U. S. Dept. of Agriculture, and provides a needed supplement to the report of 1934 which considered only pasture experiments in the humid and irrigated sections of the United States. (N. B. This report will appear in an early number of the JOURNAL.)

If the committee is continued, it is intended to take up next the presentation of a pasture research program for the future, or more specifically, a statement of pasture problems which need investigation and in connection therewith recommendations for coordinating pasture research in various sections of the United States. It is believed that certain state experiment stations and research divisions of the U. S. Dept. of Agriculture are especially well qualified, because of existing trained personnel and equipment, to solve some particular type of problem. A

suitable assignment of each important problem might thus be effectuated so as to complete the entire program. There is little doubt that each agency would voluntarily accept responsibility for some definite problem which was obviously important in their section, if a reasonable distribution of the attendant work and expense could be devised so that such duties would not interfere with their immediate and more local activities. The Bankhead-Jones funds provide at this time an especially favorable opportunity to engage in such a comprehensive attack on the task of developing our long-neglected pasture resources to a point where they would make much more nearly their potential contribution to a successful agricultural program.

L. F. Graber — George Stewart
A. E. Aldous — Paul Tabor
B. A. Brown — H. N. Vinall, *Chairman*

FERTILIZERS

Prof. R. M. Salter, *Chairman*, presented the report of the Committee on Fertilizers which, upon motion, was adopted as follows:

The Committee on Fertilizers comprises three sub-committees dealing respectively with fertilizer application, fertilizer reaction, and soil testing. The work of the committee has been directed along these three lines which later will be given separate consideration in this report.

The entire Committee held a two-day joint meeting with the National Joint Committee on Fertilizer Application in Chicago on December 3 and 4. At this meeting separate sessions were devoted to reports and papers covering the work on fertilizer application, fertilizer reaction, and soil testing. These were open meetings and the large attendance, 60 on December 3 and 123 on December 4, indicates a wide interest in the work of the Committee.

At a meeting of the Committee as a whole on December 3, the need for enlarging the scope of the Committee's activities was discussed, and it was voted that the Executive Committee of the Society be asked to give consideration to the appointment of two additional sub-committees, one to study the symptoms of mal-nutrition in plants and to prepare reproductions in color, together with accurate descriptions of such symptoms, with the thought that a book or monograph may be published when the material has been assembled. Another sub-committee is suggested to study plant-food ratios with the idea of making recommendations that will be helpful in the selection of fertilizer grades.

The Sub-committee on Fertilizer Application has functioned as one of the constituent sub-committees of the National Joint Committee on Fertilizer Application. During the year, under the sponsorship of the Joint Committee, studies of machine application of fertilizers have been conducted at 44 locations in 15 states, involving the following crops: snap, lima, and white beans, cabbage, corn, cotton, kale, peas, potatoes, spinach, sugar beets, tobacco, and tomatoes. Detailed reports of these studies will be published in the *Proceedings* of the Eleventh Annual Meeting of the National Joint Committee on Fertilizer Application which may be obtained from H. R. Smalley, Secretary of the Joint Committee.

At the meeting of the Joint Committee on December 4, a sub-committee was appointed and plans were considered for the dissemination of the results of the fertilizer application studies to farmers.

The Sub-committee on Fertilizer Reaction held a meeting in Pittsburg in December at which an agreement was reached upon the following objectives:

To study the controversial details of the method of chemical appraisal proposed by Pierre so that an analytical method might be proposed for approval by the Association of Official Agricultural Chemists.

To determine the efficiency of materials suitable for use as neutralizing agents in fertilizers with regard to the kind of material and the particle size.

The results of experimental work conducted according to plans formulated by members of the sub-committee were summarized and presented to the A. O. A. C. in November. The Association accepted the recommendations of the sub-committee and approved Pierre's method of analysis.

A program of six papers was arranged and presented at the general meeting on December 3.

The Sub-committee on Soil Testing held an informal meeting at Pittsburg in December, 1934, and set up the following five principal objectives for its work:

1. Collection and storage of a series of soil samples of known history and fertilizer response for use by investigators working on the development and improvement of methods and by service men for checking their testing technic.

2. Encouragement of the experiment stations in the study and comparison of the various rapid soil tests on their own fertility plats.

3. Presentation of a soil testing program at the 1935 meeting of the Society in Chicago.

4. A survey in the various states to determine what soil testing service is being offered, how this service is being handled, and what agronomists consider to be the proper agencies for this service.

5. A soil testing tour to provide an opportunity for study and comparison of the various rapid soil tests under different soil and climatic conditions and with different types of farming.

A full day's program, consisting of seven papers was presented at the committee meeting on December 4.

As a whole, it is believed that gratifying progress has been made toward the attainment of the objectives set up.

ROBT. M. SALTER, *Chairman*

STUDENT SECTIONS

Dr. H. K. Wilson gave the report of the Committee on Student Sections and announced the winners in the essay contest as follows:

During the past year, three additional chapters have joined the Student Section of the American Society of Agronomy. The institutions with chapters are:

Brigham Young University, Iowa State College, Kansas State College, Oklahoma A. & M. College, University of Illinois, University of Minnesota, University of Nebraska, Utah State College, Texas A. & M. College.

On December 1, the Student Section held its first meeting as a group. At this meeting 27 students representing five institutions were present. Officers were elected and plans were made for next year's work. The group expects to hold an annual meeting each year probably at the time of the Intercollegiate Crops Judging Contest.

Ten papers were entered this year in the essay contest sponsored by the American Society of Agronomy, indicating increased interest in this activity. The essays were judged by Professor A. L. Frolik, University of Nebraska, Professor J. W. Zahnley, Kansas State College, Professor G. H. Dungan, University of Illinois, and Professor T. E. Stoa, North Dakota State College. The winners of the three prizes were:

1. Kermit Greenley, University of Minnesota.
2. Horton M. Laude, Kansas State College.
3. Robert Jaccard, Kansas State College.

The committee recommends that the winning paper be published in the JOURNAL and that the Society sponsor the contest another year.

A. L. FROLIK J. W. ZAHNLEY
G. H. DUNGAN H. K. WILSON,
E. R. HENSON *Acting Chairman*

The report of the committee was adopted and checks were presented to the winners in the essay contest for first and second prizes and an annual subscription to the JOURNAL for each of the three winners. The prize-winning essay follows.

METHODS IN CORN BREEDING

Kermit Greenley, *University of Minnesota*

Although intensive corn breeding programs are now carried on by most experiment stations, possibly the first conception of the value of corn breeding was held many years ago by the Indians, who planted sèeds of different colors in the same hill with the belief that it increased yields. The corn crop has also played an important role in laying the foundation for an understanding of sexual reproduction in plants. As early as 1694, Camerarius demonstrated sex in plants thru the use of corn. Gartner in 1894 used corn extensively in his inclusive sex studies which involved nearly 700 species of plants.

In naturally self-pollinated crops, it is comparatively easy tc isolate homozygous lines by selection which, if properly handled, should remain pure. With cross fertilized crops it is not so easy to control the male parentage and therefore the improvement of this type of crop is much more difficult. In either type of crop, however, the present day methods of improvement are based on the application of genetic principles and a knowledge of inheritance.

Early Methods of Corn Improvement

Among the more significant methods of early breeding may be included mass selection, ear to row selection and F_1 varietal crosses.

Mass selection.—Mass selection consists of picking out individuals with a definite type in mind and planting this seed in a bulk increase plot. Since corn is naturally cross-pollinated, mass selection under normal conditions considers only the female parent.

Selection may be made on the basis of ear type or plant type. The selection for ear type, which is synonomously called the "Score Card Method", was extensively used about 1890 and is still in use among farmers.

Garrison and Richey (2)[1] have made a study of the effects of continuous selection for ear type. Their experiment involved six different strains of varying ear characters, i. e. smoothness, row number, ear length, and indentation. Continuous selection was practiced for 8 years. To quote from their report, the following statements are made:

"Without regard to reason, it is evident that close selection to any type, as practiced in their experiments, resulted in decreased productiveness.

"In their practical application the experiments indicate that a decrease in vigor and productiveness similar to that following inbreeding may result from too close a selection for a particular kind of ear."

[1]Figures in parenthesis refer to "Literature Cited", p. 1024.

Hayes and Garber (4) point out that although Kiesselbach (8) obtained some benefit from the selection of long, slender, smooth seeded ears compared to rough or original seed, it is doubtful whether under any circumstances continued selection for any particular type of ear is desirable. Selection in the field from vigorous, healthy stalks appears to be a better procedure than ear selection and if long, slender, smooth ears are desirable field selection will lead to the production of this type.

Ear-to-row selection.—This type of corn improvement was first introduced by Hopkins of the Illinois Experiment Station in 1899. This method differs from mass selection in that a progeny test is made from each selected ear. Several modifications of the ear-to-row method have been devised. Williams' (14) method was to plant one-half the seed of each ear that was used for the ear-to-row test. The remnants of the ears whose progeny excelled in yielding ability were planted and the progeny intercrossed. Another feature of Williams' plan was to influence several breeders to work with the same variety so that new blood could be introduced into the ear-to-row plot every fourth or fifth year from a grower who was using the same breeding method. This was a cumbersome method, involving the use of a yearly plot for the ear-to-row test, an isolated plot for the crossing of remnants, a multiplication or seed plot, and a general field. Montgomery (10) suggested a plan which eliminated some of these difficulties. His plan was to grow an ear-to-row plot only once in several years and in the intervening years use a bulk seed plot planted by the hill method, selecting only from the vigorous stalks in perfect stand hills.

Kiesselbach (8), from studies on the effect of ear-to-row breeding on the yield of Haynes Yellow Dent concluded that no method of selection gave striking increases in yield. Hayes and Alexander (3) carried on studies with Rustler White Dent but the differences obtained were insignificant.

Ear-to-row breeding may be an effective method of improving a variety which has not been systematically selected, but in general it cannot be recommended as a means of increasing the yield of well adapted varieties. Smith and Brunson (13) concluded that mass selection was a far more effective simple method of selecting corn for yield.

Varietal crosses.—As early as 1876 Beal of the Michigan Agricultural Experiment Station called attention to the larger yields frequently obtained in the first generation after crossing two varieties of corn, and suggested that such F_1 crosses or hybrids might be used to obtain increased corn yields. Renewed interest in this subject was aroused as a result of publications of East (1) and Shull (12) on the effects of inbreeding and cross-breeding.

Many experiments with F_1 crosses compared to their parents have been made. Hayes and Olson (5) studied F_1 crosses over a five year period and found that on the *average* F_1 crosses yielded about the same as the *average* of the parents.

Hayes and Alexander (3) state, "Except for special conditions, it appears that F_1 varietal crosses are of no material value as a means of increasing yielding ability, provided a broad method of breeding is used without too close selection to type."

From a general survey of the early methods used in corn improvement, it is evident that none of these methods gave sufficient increases in yield or improvement in desirable plant or ear characters to warrant their continued use. From the standpoint of corn adaptation to shorter growing seasons, mass selection on the basis of early maturity has been of outstanding value. In Minnesota and other states on the northern edge of the corn belt, early strains from varieties are now

being successfully grown which would not have been obtained without concentrated mass selection for earliness.

Present-Day Methods of Corn Improvement

The present day method of corn breeding has been defined by Richey (11) as a systematic effort to improve the crops by controlling the parentage of the seed.

East and Shull (1) (12) developed the method of breeding by controlled pollination as a result of their studies on the effects of inbreeding maize. They first began their studies in 1905, and in 1909 concluded that inbreeding was not harmful in itself because only the development of the plant was affected.

Shull (12) classified corn breeding into two headings. 1. Finding the best pure lines, and 2, the practical use of the pure lines in the production of seed corn. The problem of the corn breeder, therefore, was to produce inbred lines and find the best hybrid combinations between them.

Jones (6) explained hybrid vigor as being due to the interaction of dominant favorable growth factors, part of which were supplied by each parent.

Hayes (4) in reviewing the corn breeding situation in 1926 stated, "It is apparent that present day problems are concerned chiefly with the reaction of selfed lines and F_1 crosses between them."

Effects of Inbreeding

The effects of inbreeding may be discussed under three sub-headings.

Reduction of vigor.—All experiments have shown that reduction in size occurs in all parts of the plant as well as a decrease in productiveness and growth.

The actual decrease in productiveness varies greatly among inbred lines—some become so greatly weakened that they cannot be propagated. At the Minnesota station inbred lines of Golden Bantam sweet corn tend to be relatively more vigorous than field corn lines after comparable years of inbreeding.

Isolation of biotypes.—Together with reduction of vigor, strains having certain individual characteristics are obtained. For example, among inbred lines are found those having differential resistance to smut and root rot, varying degrees of resistance to lodging and stalk breaking, variation in time of maturity, diverse types varying in plant growth, ear character, etc These various strains form the fundamental basis for selection of the most desirable types for use in hybrids.

Appearance of abnormalities.—In the process of inbreeding, many recessive plant and ear abnormalities which are normally present but masked by the dominant allelomorph appear in their homozygous recessive condition. Thus upon continued inbreeding those plants which develop undesirable fixed characters such as albino or pale green seedling, partly formed or malformed ears, etc. may be discarded.

Use of Inbred Lines

Since it has been shown that inbred strains are reduced in vigor, it is necessary to find the proper combination of selfed lines to recover the vigor lost during the inbreeding process and to utilize the desirable characters obtained by selection.

Various types of crosses have been studied; each type is briefly discussed below.

Single crosses.—This type of cross involves only two inbred strains, and the first crop between them is used for the commercial crop.

The utilization of single crosses for the commercial crop is in general handicapped because of the small and irregular seeds obtained from the reduced, non-vigorous, inbred plants, also, as most inbred strains are low in productiveness, the cost of the seed is great as long as inbred strains are used to produce the seed for the commercial crop. Inbred lines, however, can be used to produce commercial single crosses when their vigor is comparatively high.

In sweet corn, where uniformity of maturity, ear type, etc. is very important the use of single crosses offers exceptional advantages, since the normal open pollinated varieties are very variable in these characters. Thus the use of single crosses in sweet corn is a very effective way of increasing yield, along with uniformity of ear type and maturity so highly desired by the commercial canner.

Double crosses.—The double cross plan first suggested by Jones (6) overcomes most of the difficulties of the single cross. In making this cross, four selfed lines must be used. If these lines are designated as a, b, c and d, then a is crossed with b, and c with d. The two single crosses are then planted side by side in an isolated plot and one cross is detasseled to produce the double crossed seed on the detasseled parent. Since only vigorous F_1 crosses are used it follows that the seed will be of better quality and in greater quantity than when inbred lines are used. By this plan it is necessary to make three crosses; two crosses to obtain the two single crossed parents and the final double cross. Kiesselbach (9) has shown that advanced generation single crosses may be used instead of first generation single crosses as parents for the double cross. The use of an advanced generation single cross as a female parent is, however, not advisable since the yield of double crossed seed will be considerably reduced. Advanced generation single crosses are being used successfully at Minnesota as pollen parents with first generation female parents. This plan reduces the number of crossing plots to two since the advanced generation pollen parent is increased by sib pollination in the final crossing plot.

Three-way cross.—The procedure in this type of cross is to use a single cross as a female parent with a vigorous inbred line as pollen parent. Obviously it reduces the number of crosses to two; one for making the single cross and the other for the final hybrid. This method has the further advantage that only 3 inbred lines need be carried.

The results obtained from the present day methods of corn breeding have shown conclusively that increased productiveness and improvement in other desirable agronomic characters are far in excess of those obtained by the older methods of corn breeding. The method offers exceptional opportunity for the production of hybrids of specific characteristics by the proper selection of the inbred parents.

Since hybrid seed must be produced for each commercial crop grown, this plan opens new fields for the commercial production of hybrid seed corn. Many seed companies and farmer seedsmen are now engaged in this type of work.

Modern corn breeding methods are an excellent example of the possibilities for the application of sound genetic principles in the improvement of one of the most important farm crops in the United States.

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CHILEAN NITRATE RARER ELEMENT RESEARCH AWARD

Prof. R. I. Throckmorton, *Chairman*, presented the following report for the Committee on the Chilean Nitrate Rarer Element Research Award:

The Society accepted the responsibility of sponsoring a $5,000 award for research on the rarer elements in agriculture at the annual meeting in 1934. The award is made by Chilean Nitrate of Soda Educational Bureau. Eleven candidates were considered by the Committee. Three candidates were unanimously selected to receive the award.

The Committee wishes to remind the recipients that one of the rules under which the awards are made states that they are to be used in furthering research on the rarer elements or for professional advancement.

The recipients of the award are Dr. J. S. McHargue, University of Kentucky, Lexington, Ky; Dr. Anna L. Sommer, Agricultural Experiment Station, Auburn Ala.; and Dr. L. G. Willis, University of North Carolina, Raleigh, N. C.

Dr. J. S. McHargue, Head, Department of Chemistry, Kentucky Agricultural Experiment Station, Lexington, Ky., is recognized because of his excellent and extensive research on the occurrence of rarer elements in soils and plants. He has shown tremendous insight and initiative in pursuing research studies on the rarer elements. His work has undoubtedly been inspiring to other investigators.

Dr. Anna L. Sommer, Associate Soil Chemist, Agricultural Experiment Station, Auburn, Ala., is recognized because of the quantity and quality of her research work with the rarer elements, and because she has explored new fields in this line of study. Her work has been an inspiration to other workers and the research methods which she has devised have been helpful to others.

Dr. L. G. Willis, Soil Chemist, North Carolina Agricultural Experiment Station, Raleigh, N. C., is recognized because of the very extensive information on the rarer elements which he has given to agricultural science, and particularly for the work which he has done on soils and the relation of the rarer elements to plant growth.

H. H. ZIMMERLEY	J. G. LIPMAN
A. T. WIANCKO	OSWALD SCHREINER
C. F. SHAW	R. I. THROCKMORTON
	Chairman

RESOLUTIONS

Prof. F. D. Keim, *Chairman*, presented the report of the Committee on Resolutions which was adopted as follows:

Following the procedure established with the appointment of a standing committee on Resolutions, your committee has continued, as one of its functions, to take note of the death of agronomists who have long been active in their lines of work. It is with sorrow and a feeling of great loss, therefore, that we must record the deaths since the last meeting of the Society of John S. Carroll, Jackson, Miss.; S. H. Essary, Agricultural Experiment Station, Knoxville, Tenn.; C. S. Marbut, Division of Soil Survey, U. S. Dept. of Agriculture, Washington, D. C.; G. B. Mortimer, College of Agriculture, Madison, Wisc.; and J. D. Tinsley, a charter member, Amarillo, Texas. A statement regarding the life and work of these men is made a part of this report.

JOHN S. CARROLL

In the sudden passing of John S. Carroll on September 15 at his home in Jackson, Mississippi, the fertilizer industry loses one of its oldest and best-known members. For more than thirty years, this Southern gentleman of the "old school" had been associated with the potash interests in agricultural and scientific work, and his friends, not only among scientific agriculturists but among the trade, were legion.

John Sharkey Carroll was born in Oktibbeha county, Mississippi, in 1871 and reared on a farm. He studied agriculture at the Mississippi Agricultural College, graduating in 1892 with the degree of Bachelor of Science.

He taught in the public schools of that state for two years and was then appointed instructor at the Mississippi Agricultural College, where he pursued graduate work in agricultural chemistry, receiving in 1896 the degree of Master of Science. One year was spent in graduate work in Chemistry at the University of Chicago.

In 1896 he was appointed to the position of Assistant Professor of Chemistry in the Mississippi Agricultural College and Assistant State Chemist with work in connection with the inspection and analysis of fertilizers. He continued in this work until 1904, when he accepted the position of manager of scientific and educational work of the German Kali Works for the southern states with offices in Atlanta, Georgia. Since then, with the exception of the late war period during which time he taught chemistry at the Mississippi Agricultural College, Mr. Carroll had been connected with the agricultural and scientific work of the potash interests, and at the time of his death was manager of the Southwest Territory for the American Potash Institute.

Mr. Carroll was a member of the American Association for the Advancement of Science, the Association of Southern Agricultural Workers, the American Society of Agronomy, American Chemical Society, and several other agricultural societies. He was also a member of several local organizations, including the Chamber of Commerce, University Club, and the Rotary Club. He is survived by Mrs. Carroll and daughter.—AMERICAN POTASH INSTITUTE, INC.

SAMUEL HENRY ESSARY

In the death of Samuel Henry Essary, the University of Tennessee has lost a capable and useful investigator. The summons came quickly and quietly at the home of a friend in Trenton, Sunday morning, April 28, 1935, following a busy

day at the West Tennessee Experiment Station at Jackson. Such an end he doubtless would have chosen, had choice been possible.

A native of Henderson county, he graduated from the University of Tennessee in 1897. He took his Master's at this institution in 1907, and also spent some time in study at the University of Wisconsin. He taught at LaGrange College, Missouri, 1899–1901, and at Brenau College, Gainesville, Ga., 1902–1904; became associated, in 1904, with the late Professor Samuel M. Bain, head of the department of Botany of the University of Tennessee and the Experiment Station; was assistant in that department until 1919; and was then appointed to the position of Station Botanist, which he held until the time of his death.

Mr. Essary was recognized as one of the outstanding botanists of the South, a true naturalist and keen observer. He had a deep and abiding appreciation of the beautiful and good—in nature, music and literature—and a strong sense of loyalty that endeared him to all who knew him.

One of his first achievements in plant improvement work was the development, in cooperation with Professor Bain, of Tennessee Wilt-Resistant clover, which continues to be the best variety south of the Ohio River. Before its introduction the growing of red clover in Tennessee and other parts of the South had largely ceased because of the ravages of the anthracnose disease. Two wilt-resistant varieties of tomatoes—Tennessee Pink and Tennessee Red—selected by Mr. Essary, have been of inestimable value to growers in the trucking area of West Tennessee. Probably his most important contribution to agriculture is the Tennessee No. 76 lespedeza, developed from the common Japan clover, and now grown throughout the state as a hay and pasture crop.

For a number of years he had given special attention to the improvement of cotton by selection and breeding, having made over three hundred crosses with seven of the most promising varieties, in an effort to secure superior strains—high yielding and of high quality staple. Trice cotton, one of the best early varieties now grown along the northern border of the cotton-producing area, was improved and introduced to general use by him. In all his work he maintained a high scientific standard, while achieving results of great practical value. He will be long remembered by both botanists and farmers.

Mr. Essary was a Fellow of the American Association for the Advancement of Science; a member of the American Society of Agronomy, the American Genetics Association, the Tennessee Academy of Science, the American Phytopathological Society, and the Barnard Astronomical Society; a member of Phi Kappa Phi, Alpha Zeta, and S. A. E. Fraternities, and of the following Masonic orders: Masters Lodge No. 244, Pearl Chapter No. 24 R. A. M., Knoxville Council No. 75, Cour de Lion Commandery No. 9, and Kerbela Temple A. A. O. N. M. S., all of Knoxville. He was a member of Union Baptist Church of Chesterfield, Tennessee.

Mountain hiking was one of his hobbies, He was a pioneer in the blazing of trails in the Great Smokies, now a National Park. Pictures of peaks and studies of plant life made by him have been used in books that describe the Smoky Mountain area.

Mr. Essary was a gentleman. His unassuming, helpful, and sympathetic nature and his genial personality won for him many friends, who are deeply grieved at his going. He was a well loved figure at the University, and will be greatly missed, particularly by his associates in the Experiment Station and the College of Agriculture.

"A short life is given us by nature; but the memory of a well-spent life is eternal." His work stands as a monument to his life.—E. G. Frizzell.

CURTIS FLETCHER MARBUT

By the death of Curtis Fletcher Marbut, at Harbin, Manchukuo, on August 25, 1935, the American Society of Agronomy lost a loyal member and science one of its most distinguished authorities on the soils of the world.

Dr. Marbut was born on a farm in Lawrence County, Missouri, July 19, 1863. His early education was acquired in the short-term rural school of the community, and after securing a teacher's certificate he spent a brief time teaching in the rural schools during which period he prepared himself for college. A year after his graduation from the University of Missouri in 1889, he was appointed to the staff of the Missouri State Geological Survey and after spending a year in post-graduate work he received a master's degree from Harvard University in 1894. From 1894 to 1897 he was instructor in geology at the University of Missouri, assistant professor from 1897 to 1899, and professor from 1899 to 1910. In 1905 Dr. Marbut assumed directorship of the soil survey of the state and five years later left his native state to take active charge of the Federal Soil Survey project which had been inaugurated some years earlier by Dr. Milton Whitney. During the quarter of a century that followed, the area surveyed and mapped in detail and in reconnaissance increased from approximately 200 million acres to about one billion acres or substantially one-half of the land area of the United States. Under his direction the Soil Survey became one of the outstanding scientific undertakings of the Department of Agriculture. His scientific and scholarly approach to the subject gave great impetus not only to the soil work in this country but to soil research throughout the world. The detailed reports and maps of the areas that have been distributed during the progress of the survey has been supplemented by a single volume recently completed by Dr. Marbut. This volume, giving an inventory of the soil resources of the nation, which has just been published as Part III of the Atlas of American Agriculture will stand as a monument to his industry and perseverance in his chosen field of science.

Dr. Marbut's interest and knowledge of soils was not confined to his own country and even at the time of his death he was on his way to China for the purpose of assisting the Chinese Government in making an inventory of its vast soil resources. He had previously made personal examination of the soils of every country of Western Europe except those of Spain. He was also familiar with the great soil groups of Russia and had made trips into Africa and South America for the purpose of studying and classifying the soils of extensive regions on these continents. He consistently visualized the study of soils as an international problem and his wide experience had brought him recognition as one of the world's foremost authorities in the field of pedology. During the meetings of the First International Congress of Soil Science held in this country in 1927, he participated in practically all of the international undertakings for the promotion of soil classification including fundamental studies of soil genesis and morphology. At the Second International Congress held in Russia in 1930 and again at the Third Congress at Oxford, England in 1935, he rendered conspicuous service in defining the fundamental and universal processes of soil formation and assuring leadership in outlining the scope and purpose of soil science as a definite field of scientific endeavor.

In addition to those already mentioned, many honors came to Dr. Marbut including the LL.D. degree from his Alma Mater and the degree of D. Sc. from Rutgers University in 1930 conferred upon him at the celebration of the semicentennial of the establishment of the New Jersey Agricultural Experiment Station. During the same year he received the Cullum Medal of the American

Geographical Society for his geographic work on the soil, "the foothold of all things". In addition to his membership in the American Geographic Society he was an honorary member of the Royal Geographic Society of Berlin and the Czechoslovakian Academy of Soil Science. He served as president of the Association of American Geographers in 1924 and was chairman of Section O of the American Association for the Advancement of Science in 1926. He was active in the organization of the American Soil Survey Association and in 1928 was made a fellow in the American Society of Agronomy.

Dr. Marbut had passed the age of retirement but had been retained for the third additional year in order to enable him to continue important researches on the morphology and classification of the soils of this and other countries and to prepare for publication the results of some of his recent studies.

In closing this brief sketch of the life of my dear good friend, I cannot do better than to quote from a letter written from Harbin the day following his death:

"To me he was a great and good teacher, which, according to Chinese traditions is next to being a father. He had such a great and contagious enthusiasm for his work that the men under him, and even those who sometimes disagreed with him, caught the contagion and were inspired to greater achievements. One of the greatest things about his nature was that, while he had strong convictions regarding the various phases of his investigations, he was always willing to change his views when convincing proofs were brought forward. He often asked to 'see the documents', but if the latter were convincing, he was ready to concede the point. It is truly amazing, however, that he was so seldom on the wrong track and nearly always considerably ahead of his colleagues. Glimpses of his wholesome and well balanced philosophy of life at various times and under different circumstances are a precious memory. A young or middle-aged man who has not had the friendship of an elderly man of Dr. Marbut's rare type is spared the grief which comes with his loss, but his life is also lacking in one of the greatest joys."—A. G. McCall.

GEORGE B. MORTIMER

G. B. Mortimer, Professor of Agronomy, Wisconsin College of Agriculture, passed over the Great Divide to receive the reward that is due him for his strenuous labor in behalf of agriculture throughout life. Professor Mortimer was known far and near throughout the University and the State of Wisconsin as a firm friend to the farmer and young people of the state. All classes of people miss him and think of his great worth while with us.

Brought up on a farm in the early days, he learned the habits of industry which continued with him throughout life. A thorough teacher, a great investigator, and one who has performed duties that will live for many years after his departure. Never was there a man in the history of our country that took a deeper interest in the work he had to perform than George B. Mortimer. His students were always welcome to come and see him and no matter how busy with technical affairs, he would always throw the work aside in order to give his students encouragement. He was considered one of the best teachers in the state University and his extension work was marked by exactness and practicability of presentation of subject. Professor Mortimer was one of the few individuals who could always speak to a farm audience in a language which all could understand. He avoided high technical terms as he felt that they meant very little, if anything, to the farmers. His work on pastures during the past six or eight years has given the world many new things to think about. It is too bad to lose men of this

character when we need their services so badly. However, he has left us, but his work will go on for many years to come.—R. A. MOORE.

JOHN DABNEY TINSLEY

John Dabney Tinsley was born September 22, 1869, at Charlottesville, Va., and died in Amarillo, Texas, on August 5, 1935.

He attended the Miller School for boys in Albemarle County, Va., and after graduation from the University of Virginia returned to teach in that school for five years. In 1896 he joined the faculty of the New Mexico A. & M. College as professor of biology and two years later was put in charge of the irrigation investigations of the experiment station. In 1899 he organized a department of soil physics in the college and station and continued as head of the department until 1910, when he was named agricultural demonstrator for the Atchison, Topeka, and Santa Fe lines in New Mexico, with headquarters at Albuquerque. In 1913 he was transferred to Galveston, Texas, as agricultural agent for the Gulf, Colorado, and Santa Fe Railway Company. In 1923 he moved to Amarillo, Texas, to become General Agricultural Agent for the Panhandle and Sante Fe Railway Company and continued in this capacity until the time of his death.

Mr. Tinsley was a charter member of the American Society of Agronomy, a fact to which he often referred with pride, and he maintained his membership in the Society to the time of his death. He was first and last a scientist and won and held the esteem of his associates by his tolerant and patient attitude toward all with whom he came in contact.—N. H. MOHLER.

The Resolutions Committee, acting upon a request from the American Soil Survey Association, also recommends that the American Society of Agronomy approve the suggestion embodied in the report of the Committee on Soil Conservation of the American Soil Survey Association that a soil survey of unsurveyed agricultural lands be completed as rapidly as possible and on a national scale as being of fundamental importance in national and state land planning programs.

G. E. RITCHEY S. B. HASKELL
E. F. GAINES J. D. LUCKETT, *ex officio*
F. D. KEIM, *Chairman*

OFFICERS' REPORTS

REPORT OF THE EDITOR

Prof. J. D. Luckett, Editor, presented his report which upon motion, was accepted as follows:

It is our pleasure to submit herewith probably the most favorable report on the state of the JOURNAL that it has been our privilege to prepare for many years. This feeling of satisfaction is not due so much to the fact that the 1935 volume is particularly outstanding in size or quality; for in these respects it is probably just a good average volume of the JOURNAL. The satisfaction is found rather in the fact that the somewhat rigid restrictions that were set up two years ago to meet an acute emergency in the affairs of the JOURNAL have apparently served their purpose and might well be removed, at least in large measure, in 1936.

To make this report as brief as possible, we would state simply that in the 1935 volume we shall have 123 contributed articles, 12 notes, and 14 book reviews—a slight falling off from 1934 in number of contributed papers, but the two vol-

umes will compare almost page for page in size. There are on hand at this time just sufficient papers to complete the January number of the JOURNAL, hence we are prepared to offer as prompt publication in 1936 as one may reasonably expect from a monthly journal.

Coupled with this favorable publication schedule is a fairly satisfactory financial situation, about which the Treasurer will give you more detailed information, all of which leads to the belief on the part of the Treasurer, the Editorial Advisory Committee, and myself that we may safely return to a more nearly normal basis of operation in the management of the JOURNAL next year.

Specific recommendations made to the Executive Committee, therefore, include the following points:

1. An increase in the number of pages of free publication allowed each contribution in the JOURNAL from the present limit of 8 pages to a new limit of 12 pages. In this connection you may be interested to know that of the 123 papers appearing in the 1935 volume, 89 contain 8 pages or less, while 111 contain 12 pages or less. Thus, increasing the limit of free pages to 12 will relieve a very large proportion of contributors of all restrictions on space. Also, these added pages should make possible a more comprehensive presentation of results without danger of incurring penalties for extra pages.
2. The establishment of a charge of $4.00 per page for each page beyond 12 pages to and including 16 pages; and a charge of $5.00 per page for each page beyond 16 pages.
3. An increase in the allowance for illustrations from $10 to $15 for each article.

With the opportunity for prompt publication and with most, if not all, financial restrictions removed, the JOURNAL should prove an attractive medium of publication in 1936.

The success of the JOURNAL this year, as in other years, is due in large measure to the generous cooperation of many persons who receive little or no recognition for their efforts beyond the personal satisfaction of rendering worth while service. These include the reviewers who labor over the papers submitted to the JOURNAL, the authors who accept our criticisms in such good spirit; the correspondents who supply us with timely news items; the advertisers who help pay our bills; the able and genial chairman of the Editorial Advisory Committee who guides our faltering steps; and most of all that dual-personality, the Secretary-Treasurer, who in his capacity as Secretary has the endless task of keeping our mailing lists in order, and as Treasurer must first collect and then disperse the funds that keep the JOURNAL coming to you on a regular schedule. To all of these we acknowledge a profound debt of gratitude.

In concluding this report, the thought that I would like to leave with you is that the JOURNAL has successfully weathered a really serious crisis in its affairs; that for the first time in several years we are in a position actually to encourage contributions to the JOURNAL; and that, in fact, we really should see more papers than we are seeing at the present time. We believe that this need can be quickly and easily met and are looking forward to your cooperation in this direction in the year ahead.

Submitted,

J. D. LUCKETT, *Editor.*

REPORT OF THE TREASURER

The Treasurer's report was presented, received, and referred to the Auditing Committee as follows:

I beg to submit herewith the report of the Treasurer for the year November 1, 1934, to November 25, 1935:

Receipts

Advertising income	$ 511.72	
Reprints sold	1,795.66	
JOURNALS sold	181.26	
Subscriptions, 1935	1,783.30	
Subscriptions, 1934	170.50	
Subscriptions, 1935, new	523.86	
Subscriptions, 1936	79.95	
Dues, 1935	3,524.82	
Dues, 1934	483.00	
Dues, 1935, new	700.50	
Dues, 1936	47.00	
Received on trust certificate	24.17	
Total receipts	$ 9,825.74	
Balance in cash, November 1, 1934	511.51	
Total income		$10,337.25

Disbursements

Printing the JOURNAL, etc	$ 8,003.69	
Salary Business Manager and Editor	802.68	
Postage (Secretary and Business Manager)	189.90	
Printing, miscellaneous	298.18	
Express on JOURNALS	31.48	
Mailing clerk	52.14	
Refunds, checks returned, etc	19.81	
Miscellaneous, annual meeting, etc	409.24	
Total disbursements		$ 9,807.12
Balance on hand, November 25, 1935		$ 530.13
Balance in trust certificate		296.99
Total balance in account		$ 827.12
Balance in cash on hand	$ 530.13	

Respectfully submitted,

P. E. BROWN, *Treasurer.*

REPORT OF THE ASSISTANT TREASURER

Dr. A. G. McCall, presented the report of the Assistant Treasurer, which was received and referred to the Auditing Committee as follows:

The status of the account of the American Society of Agronomy with the Executive Committee of the First International Congress of Soil Science as of November 16, 1934, to November 23, 1935, is as follows:

Receipts

Sale of Proceedings, First International Congress of Soil Science (1927)	$ 123.00	
Interest on savings account, Prince George's Bank and Trust Company, Hyattsville, Md	64.50	
Membership dues from American members of International Society of Soil Science	1,062.50	
Credit by bank for check of John T. Miller for dues included in deposit of April 4, 1935 ($100.30) returned by bank for better endorsement; endorsement was correct and check redeposited April 10, 1935	6.80	
Balance on hand, Prince George's Bank and Trust Company, Hyattsville, Md., Nov. 15, 1934:		
Savings account	2,315.20	
Checking account	117.39	
Total receipts		$ 3,689.39

Expenditures

Postage (stamps and envelopes for office correspondence, transmittal of deposits, membership records, Proceedings orders, etc.)	$ 35.08	
Rumford Press, Concord, N. H., for handling and shipping sets of Proceedings of First Congress	15.56	
Tax on checks issued (bank charge)	.10	
Exchange (deducted by bank on 2 Honolulu checks (dues))	.70	
Premium on bond for Dr. A. G. McCall, Ass't. Treasurer	5.00	
Rubber stamp for endorsement of checks	1.70	
Express charge on film of the First International Congress shipped to New York for transportation to England for Third International Congress meeting	.71	
Bank deducted for check of John T. Miller returned for better endorsement; endorsement was correct and check redeposited April 10, 1935	6.80	
Transmittal of dues collected from American members and sent to Dr. D. J. Hissink, General Secretary of the International Society of Soil Science	1,062.50	
Check No. 434 Aug. 6, 1934, $1.00; and check No. 436 Nov. 12, 1934, $1.17 (included in last year's disbursements but outstanding as of last year's bank balance; checks deducted from this year's bank balance)	2.17	
Balance on hand in bank, as of November 23, 1935 savings (includes contribution to Endowment Fund $1,000.)	2,502.70	
Balance on hand in bank, as of November 23, 1935, checking	56.37	
Total		$3,689.39

Submitted by

A. G. McCALL,

Executive Secretary, American Organizing Committee, and Assistant Treasurer, American Society of Agronomy.

RECORD OF PROCEEDINGS OF FIRST INTERNATIONAL CONGRESS OF SOIL SCIENCE

Proceedings on hand in storage with The Rumford Press, Concord, N. H., as of Nov. 15, 1934	930 sets
Sold during the period November 16, 1935 to November 23, 1935, inclusive	12 sets
Remaining in storage as of November 23, 1935	918 sets

12 sets distributed as follows:

- 2 sets at $ 5.50
- 3 sets at 10.50
- 7 sets at 11.50
- 1 Vol. IV only at $2.50

Collections as follows:

2 sets at $ 5.50	$11.00	
4 sets at $10.50 (includes 1 set ordered last year and not paid until this year)	42.00	
5 sets at $11.50	57.50	
1 set at $10.00 (a 1931 order not paid until this year; former price)	10.00	
1 Vol. IV only	2.50	
Total		$123.00

Submitted by,

A. G. McCALL,

Executive Secretary, American Organizing Committee, and Assistant Treasurer, American Society of Agronomy.

AUDITING COMMITTEE

Dr. Richard Bradfield, *Chairman*, reported that the Auditing Committee had examined the books and vouchers of the Treasurer and the Assistant Treasurer and found them correct. The report was adopted as follows:

The accounts of the Treasurer and Assistant Treasurer have been audited and approved.

H. K. Wilson
R. Bradfield, *Chairman*

REPORT OF THE SECRETARY

The report of the Secretary was presented and accepted as follows:

I beg to submit herewith my report as Secretary for the year November 1, 1934, to November 25, 1935, as follows:

Membership changes 1934–1935:			
Membership, last report			868
New members, 1935		168	
Reinstated members		35	
Total increase		203	
Dropped for non-payment of dues	61		
Resigned	14		
Died	5		
Total decrease	80	80	
Net increase		123	123
Membership, November 25, 1935			991
Subscriptions:			
Subscriptions, last report			538
New subscriptions, 1935		111	
Subscriptions dropped		110	
Net increase		1	1
Subscriptions, November 25, 1935			539

MEMBERSHIP BY STATES AND COUNTRIES

Alabama	8	Missouri	20
Arizona	13	Montana	9
Arkansas	7	Nebraska	24
California	39	Nevada	1
Colorado	22	New Hampshire	1
Connecticut	11	New Jersey	17
Delaware	3	New Mexico	10
District of Columbia	79	New York	39
Florida	13	North Carolina	17
Georgia	11	North Dakota	11
Idaho	7	Ohio	39
Illinois	40	Oklahoma	18
Indiana	23	Oregon	14
Iowa	40	Pennsylvania	22
Kansas	41	Rhode Island	7
Kentucky	11	South Carolina	8
Louisiana	15	South Dakota	8
Maine	7	Tennessee	6
Maryland	16	Texas	40
Massachusetts	10	Utah	11
Michigan	10	Vermont	2
Minnesota	25	Virginia	19
Mississippi	6	Washington	19

West Virginia	13	Germany	4
Wisconsin	27	Greece	2
Wyoming	4	Honduras	2
Hawaii	11	India	11
Philippine Islands	2	Italy	1
Porto Rico	1	Japan	6
Africa	8	Jugoslavia	1
Argentine	4	Mesopotamia	1
Austria	1	New Zealand	1
Brazil	2	Poland	1
British West Indies	1	Scotland	1
Canada	20	Siam	1
China	16	Spain	1
Cuba	3	Sweden	1
Denmark	2	Switzerland	1
Egypt	1	Turkey	1
England	3	Uruguay	1
Finland	1	U. S. S. R	6
Total			991

MEMBERSHIP BY YEARS OF ELECTION

1908 Charter	26	1922	33
1908	8	1923	22
1909	3	1924	29
1910	13	1925	60
1911	21	1926	47
1912	12	1927	38
1913	13	1928	35
1914	10	1929	69
1915	17	1930	45
1916	24	1931	52
1917	11	1932	39
1918	10	1933	37
1919	8	1934	87
1920	23	1935	168
1921	31		
Total			991

TOTAL MEMBERSHIP BY YEARS

1908	121	1918	509	1927	767
1909	129	1919	473	1928	823
1910	176	1920	436	1929	906
1911	236	1921	592	1930	943
1912	295	1922	643	1931	963
1913	349	1923	561	1932	949
1914	397	1924	577	1933	904
1915	471	1925	646	1934	868
1916	586	1926	700	1935	991
1917	652				

Submitted,

P. E. Brown, *Secretary.*

FELLOWS

Vice-president R. M. Salter announced the Fellows-Elect and presented them with diplomas. Those honored were Dr. Richard Bradfield, Dr. C. E. Millar, and Prof. A. C. Arny. (See pages 1007 to 1008 of this number of the Journal.)

ANNUAL DINNER

The annual dinner of the Society was held on Thursday, December 5, at 6:30 p. m. at the Stevens Hotel with 189 in attendance. The presidential address of Dr. H. K. Hayes was given at the dinner.

NEW BUSINESS

Upon motion of Dr. A. G. McCall, which was carried, he was authorized to send 100 sets of the *Proceedings* of the First International Soil Congress to the Secretary of the International Society for his use.

REPORT OF THE NOMINATING COMMITTEE

Dr. A. L. Patrick presented the report of the nominating committee and upon motion the report was adopted and the following officers declared elected for the next year: F. D. Richey, *Vice-president*, W. H. Pierre and T. E. Odland, representatives of the Society on the Council of the A.A.A.S. R. M. Salter automatically succeeded to the Presidency and H. B. Sprague and W. A. Albrecht were announced as elected to the chairmanships of the Crops and Soils Sections, respectively.

Meeting adjourned.

P. E. BROWN, *Secretary.*

OFFICERS OF THE SOCIETY FOR 1936

President, R. M. Salter, Wooster, Ohio.
Vice-President, F. D. Richey, Washington, D. C.
Chairman, Crops Section, H. B. Sprague, New Brunswick, N. J.
Chairman, Soils Section, W. A Albrecht, Columbia, No.
Editor, J. D. Luckett. Geneva, New York.
Secretary-Treasurer, P. E. Brown, Ames, Iowa.

AGRONOMIC AFFAIRS

MINUTES OF THE 1935 BUSINESS MEETING FOR THE CROPS SECTION

The meeting was called to order by Chairman R. D. Lewis. Dr. Lewis invited attention to the proposed reorganization of the Soils Section of the American Society of Agronomy. It was emphasized that this provides for continuation of close association of soils workers with crops workers. The question was raised as to the advisability of reorganizing the Crops Section along some lines similar to those being completed by the Soils Section. Dr. Lewis suggested that a study should be made of this matter.

F. D. Richey moved that the incoming committee of the Crops Section study this situation, or appoint a committee to make this study, using a method of canvassing members of the American Society of Agronomy and preparing a report similar to that used by the committee of the Soils Section. Motion seconded and passed.

Report of the Nominating Committee appointed by Chairman Lewis was presented by F. B. Bussell. Nominations for the Crops Section Committee for the coming year named O. S. Aamodt of Wisconsin, A. M. Brunson of Kansas with H. B. Sprague of New Jersey as Chairman. The report was accepted. It was moved by Dr. M. A. McCall that the Chairman cast a unanimous ballot for the nominees. The motion was seconded and passed.

Upon motion, the meeting was adjourned to make way for the regular programs. The crops programs arranged by the Crops Section Chairman included three half-day programs with a total of 28 papers

and two round-table discussion groups on corn hybrid production and distribution and forage crop improvement, respectively, with 19 persons scheduled to present reports.—H. B. SPRAGUE, *Secretary*.

THE REPORT OF THE JOINT COMMITTEE ON SOIL SCIENCE REORGANIZATION

THE report of the Joint Committee on Soil Science Reorganization was presented before the joint meeting of all interested in soil science on December 4 at the Stevens Hotel, Chicago, Ill., in the same form in which it was published in the November issue of the JOURNAL. Copies of this report were mimeographed and mailed to every American member of the American Soil Survey Association and the American Society of Agronomy early in November. A questionnaire requesting information necessary for the formulation of a satisfactory solution to the problem was attached to the report. Replies were received from 241 members of the A. S. A. who indicated that they were primarily interested in soils and from 149 members of the A. S. S. A. These replies represent approximately 50% of the men interested primarily in soils in both organizations. A summary of the replies received from the members of the two organizations is tabulated below.

SUMMARY OF REPLIES TO THE QUESTIONNAIRE ON SOIL SCIENCE REORGANIZATION

(Expressed as percentage of replies received by November 29)

Question		A. S. A.*	A. S. S. A.†
1. Are you interested primarily in			
Soils only?		44	61
Soils and Crops?		56	39
2. Are you in favor of a single soil science organization	Yes	92	95
in the United States?	No	8	5
3. Do you feel that a close affiliation between Soils and	Yes	90	85
Crops groups should be maintained?	No	10	15
4. Do you favor a merger of the existing Soils Organizations of the general type proposed?	Yes	98	95
	No	3	5
5. Would you favor the publication of a volume of Pro-	Yes	89	91
ceedings to include papers presented at the annual meeting?	No	11	9
6. Would you subscribe for such a volume of 1936 Pro-	Yes	85	91
ceedings if it could be published for $4.00–$4.50?	No	15	9
7. Would your subscription to the Proceedings prevent	Yes	17	10
your subscription of the JOURNAL?	No	83	90
8. What name would you prefer for this Soil Science Organization?			
Am. Assn. of Soil Scientists		15	18
Am. Soc. of Soil Science		51	66
Soils Division of A. S. A.		34	16
9. In which of the proposed Soil Science Sections would you be interested?			
Physics		45	51
Chemistry		64	63
Biology		42	30
Fertility		84	67
Morphology		44	68
Technology		51	61

*Based on 241 replies received from men interested in Soils. Does not include men interested primarily in Crops.

†Based on 149 replies received from a total of 290 members or 51% of total membership.

After prolonged discussion, the proposal "that the A. S. S. A. and the Soils Section of the A. S. A. unite to form a single organization which shall be called the American Society of Soil Science" was approved at the joint meeting by a vote of 88 to 10. The balance of the report was approved with only slight modification and referred to the A. S. S. A. and the Soils Section of the A. S. A. for ratification. The action taken at the joint meeting was unanimously ratified by the A. S. S. A. at a called business meeting on December 5 and at the regular business meeting of the Soils Section of the A. S. A. on the same date. Each organization reappointed its two representatives on the joint reorganization committee and instructed this committee to draft a constitution for the proposed American Society of Soil Science in accordance with the principles already approved. Copies of this constitution were ordered to be brought to the attention of the members of both organizations in advance of the next annual meeting so that the final action necessary to put the plan in operation can be taken at the 1936 annual meeting. A mail ballot on this constitution was requested in the A. S. S. A. A second joint committee was appointed to formulate editorial policies for the proposed *Proceedings*.

NEWS ITEMS

H. W. BENNETT was recently appointed Associate in Agronomy, Forage Crops, Mississippi State College. He will devote his time to research, primarily with the selection and breeding of forage and soil improving crops.

I. E. MILES was recently appointed Associate in Agronomy, Soils, Mississippi State College, where he will devote half of his time to the teaching of Soils and half to research work in the relative symbiotic nitrogen fixation of several legumes.

THE AMERICAN POTASH INSTITUTE, INC., is announcing the appointment of R. G. Pridmore as Assistant Agronomist at its headquarters in the Investment Building, Washington, D. C. Mr. Pridmore was for the past 5 years Assistant Agronomist on the staff of the Georgia Agricultural Experiment Station.

H. M. BAINER has been appointed General Agricultural Agent for the Panhandle and Santa Fe Railway Company with headquarters at Amarillo, Texas.

J. H. CHRIST, Superintendent of the Sandpoint Idaho Experiment Station, has resigned to become Agronomist with the Soil Erosion Service, Colorado Springs, Colo. He has been succeeded by Ralph H. Knight, a graduate of the University of Idaho.

H. W. HULBERT, Agronomist and Head of the Department of Agronomy, University of Idaho, has resigned effective January 1, 1936, to become associated with the Mark Means Company, Seedsmen of Lewiston, Idaho. Mr. Hulbert has been connected with the Idaho Experiment Station since 1917.

M. J. BUSCHLEN, a graduate of Michigan State College, has been appointed Field Superintendent in Agronomy at the Idaho Station.

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